CIVIL ENGINEERING

JOINT HIGHWAY RESEARCH PROJECT

JHRP-76-22

THE USE OF SKEWED SPEED DISTRIBUTIONS TO LOCATE POINTS OF HIGH ACCIDENT POTENTIAL ON LOW VOLUME TWO-LANE RURAL HIGHWAYS

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PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Final Report

THE USE OF SKEWED SPEED DISTRIBUTIONS TO LOCATE POINTS
OF HIGH ACCIDENT POTENTIAL ON LOW VOLUME
TWO-LANE RURAL HIGHWAYS

TO:	J. F. McLaughlin, Director Joint Highway Research Project	August 3, 1976
		Project: C-36-59R
FROM:	H. L. Michael, Associate Director Joint Highway Research Project	File: 8-5-18

The attached report titled "The Use of Skewed Speed Distributions to Locate Points of High Accident Potential on Low Volume Two-Lane Rural Highways" is submitted as the Final Report on the approved JHRP Study of similar title approved in March 1973. It has been authored by Mr. Robert J. Krzeminski, formerly Graduate Assistant in Research on our staff under the direction of former Professor Roy Loutzenheiser and Professor H. L. Michael. Mr. Krzeminski accepted a position with the Florida Department of Transportation before completion of this Study and hence it has taken him longer than normal to complete the research.

The research investigated a hypothesis proposed by Mr. Krzeminski that locations of high accident potential could be determined by the Coefficient of Skewness (C.S.) of the spot speed distribution on the immediate approach to the site. The hypothesis was shown in the research to be valid and a value of C.S. above which a high number of accidents will likely occur is proposed. The research findings are important as they provide a means of locating where a high number of accidents will likely occur before they do occur.

The report is presented to the Board for acceptance as fulfillment of the objectives of the approved Study.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

HLM:ms

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by

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Project No.: C-36-59R

File No.: 8-5-18

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana State Highway Commission

Purdue University
West Lafayette, Indiana
August 3, 1976

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Professor Harold L. Michael, Associate Director of the Joint Highway Research Project, for his guidance and assistance during the development of this study, and for his expert review of the manuscript. His appreciation also goes to Professor Roy Loutzenheiser who directed the study during its initial months and who also reviewed the manuscript. In addition, the author wishes to express his appreciation to Professors Gilbert Satterly and Virgil Anderson for their reviews of the manuscript and their assistance in developing the final report. The author also wishes to express his appreciation to Mr. George Stafford who was of great assistance with the data collection.

A special expression of appreciation must be given to my wife, Sandra, for her constant encouragement and for her many long hours of typing, editing and correcting. Without her help, this document could have never been finalized.

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ABSTRACT

Krzeminski, Robert Joel. MSCE, Purdue University, August 1976. The Use of Skewed Speed Distributions to Locate Points of High Accident Potential on Low Volume Two-Lane Rural Highways. Major Professor: Harold L. Michael.

The objective of this research was to determine if a correlation exists between skewed speed distributions and points of high accident potential. To achieve the objective, spot speeds and accident data were studied at twelve sites during daytime hours and five sites during nighttime hours. All sites were on rural two-lane highways.

A perception-speed concept of driver responses to a potential accident situation was developed. This concept examined a driver's reaction to a potential hazard based on his personal perception of the hazard and on the forces he had at his disposal to avoid the hazard. It was shown that where a driver had a particular difficulty in perceiving the hazard or where he perceived the hazard incorrectly, the probability of an accident occurring was greater. The findings of this research tend to support the hypothesis made in the development of this concept.

It was found that sites having high accident frequency histories also exhibited skewed speed-frequency distributions. Sites having low or no accident histories exhibited normal speed-frequency distributions. The comparison of the day and

night data and directional data found that while certain parameters such as mean speed and deviation did change, the relative shape of the frequency distribution curve did not if perceptual accuracy did not change.

This research proposes that the test and analysis procedure developed should be employed to find areas of perceptual problems prior to the occurrence of accidents and to test the effectiveness of warning or corrective measures.

INTRODUCTION

Every year, thousands of Americans will lose their lives in accidents on two-lane rural state highways. Increased auto ownership and increased travel only serve to add impetus to this increasing accident frequency.

In 1973, due to the energy crisis, the speed limit on the nation's highways was reduced from 70 to 55 miles per hour. This decrease in speed, although originally proposed for the conservation of fuel, had a secondary affect. The months following the speed limit change saw a marked decrease in the number of fatal accidents nationwide. This effect appears to be only a short-lived one however, as recent statistics tend to indicate an increase in accident frequency.

When one considers the question of why accidents occur, one of the first conclusions drawn is, "it is what you don't know that can kill you." Stating this in a slightly different manner, failure to perceive a situation correctly is the cause of many accidents. Obvious dangers are usually very apparent to a driver, thus adequate compensation can be made and an accident avoided. Following this line of thinking, it can be said that a potentially high accident frequency area will be produced in a hazardous location that gives the impression of being safe. A

driver, approaching such a hazardous location, may perceive the location to be safer than it actually is, thus he may be "over committed" into an accident.

The problem is then stated:

a. If a hazard is not obvious, how do you locate it?

b. When it is located, how do you adequately warn the driver to take adequate preventative action?

This research was oriented toward the development of a method of locating these points of high accident potential (areas with no obvious hazards) prior to the occurrence of numerous accidents. Once these "not obvious" hazardous areas have been located, corrective measures can be taken to minimize the potential danger.

The specific object of this research was to determine if a correlation between non-normal (skewed) speed distributions and areas of high accident potential does in fact exist on low volume rural two-lane highways. If this correlation does exist, the test procedure developed in this research could be implemented to locate points of high accident potential prior to the occurrence of numerous accidents. In addition, once these areas have been located, this test procedure could be used to determine the overall effectiveness of various warning methods without having to wait a period of time to study the change in accident rates.

REVIEW OF LITERATURE

A great wealth of information concerning speed studies, accident studies, and speed distributions has been written since 1950. This literature review is grouped into the following categories to separate much of the previous research into distinct groups:

1. Speed studies
2. Accident studies
3. Normal distributions
4. Geometry-Accident rate studies
5. Skewed distributions
6. Factors affecting speed distributions

Speed Studies

Oppenlander, based on an extensive literature search of about 800 sources, considers several variables that can influence spot speed characteristics. (17)* These variables are:

1. The driver
2. The vehicle
3. The roadway
4. The traffic
5. The environment

*Number refers to reference number as stated in bibliography.

Concerning the variable of the driver, Oppenlander states, "Today, few drivers attempt to attain the potential speed of which their vehicles are capable. Few drive our modern roads at the speed the surfaces permit. Their driving performance must therefore be largely dependent on their inherent personal characteristics." (17, page 10)

In his consideration of the vehicle, Oppenlander states, "As the percentage of high powered vehicles on the highway increases, the average speed of the vehicles must be slightly increased." (17, page 10) He feels that vehicular horsepower does not significantly affect spot speeds, however.

In his consideration of the effects of the roadway, Oppenlander states, "Different rates of travel result from a driver's attempt to evaluate roadway conditions and to select a safe speed." (17, page 12) What he seems to be implying here is that vehicular spot speeds will be more of a function of the way a driver perceives a roadway situation, rather than the situation itself.

Oppenlander also considers the effects of traffic and the environment on spot speeds. His findings as a result of his literature review tend to reinforce the fact that the amount of traffic is in general directly proportional to the average spot speed through the area. Environmental effects can also cause changes in the spot speeds; however, these changes again result from the way a driver perceives the particular situation.

This report seems to emphasize the fact that it is the

driver and the way the driver perceives the roadway, traffic and environment, that is the determining factor of what the speed will be at a particular point and time.

Accident Studies

The State of the Art of Traffic Safety is a literature review containing over 1800 sources in the study of accidents. (21) Little has grouped these studies into five separate categories:

1. Human factors
2. Environmental factors (including roadway)
3. Vehicular factors
4. Loss limiting factors
5. Regulatory and legal factors

Each of these factors is viewed separately by Little, and the many variables that influence each category are considered. The conclusions reached by Little are as follows:

1. Highway safety is a systems problem.
2. The concept of "cause" has little operational significance in the study of accidents.
3. There are no instant remedies for highway safety apparent in the literature.
4. Information required for improvement of highway safety is lacking.

Normal Distributions

An assumption made for this research was: given a typical

location on a section of rural state highway, under free flow conditions, one is likely to find a normal distribution of speeds about a mean. A literature search indicates that, based on prior research (6,9,10,11,12,14,15,16,17,18), this is the usual finding.

A statement made by Oppenlander sums up this portion of the literature review. Oppenlander states, "As the results of many field studies have indicated, the distribution of the spot speed data closely approximates the normal curve." (16, page 15) The initial assumption of the normality of the distribution at a typical section is verified on the basis of prior research.

Geometry-Accident Rate Studies

The literature contains many items dealing with investigations of the relationships of highway design features to accidents. This literature can be broken into two distinct groups, those which dealt with the problem in its entirety (19,7) and those which dealt with only one variable or a group of such variables.

Raff (19) studied how accident rates on main rural highways are affected by design features and use characteristics. The factors studied included:

1. Number of lanes
2. Average daily traffic
3. Degree of curvature
4. Pavement and shoulder widths
5. Frequency of curves and sight restrictions

6. Percentage of intersection traffic on minor roads

7. Others

Raff found that a number of roadway features including grade and frequency of curve do not appear to have any consistent effect on accident rates. Raff mentions that the most striking feature of this study was the amount of irregularity in most of the results. He indicated that the principle cause of this is probably the tremendous complexity of the problem itself.

Blensly (2) found that a significant relationship between increased accident frequency and increased pavement width exists. He did indicate, however, that his results should be interpreted with extreme caution inasmuch as the traffic volumes on the bulk of the sections studied were less than 5000 vehicles per day.

Belmont (1), making a study along the same lines as Blensly, found a similar relationship between personal injury accident frequency and paved shoulder width on sections with volumes between 2000 and 12,000 vehicles per day. Belmont concluded that the apparent advantages of wide shoulders are more than offset by the tendency of the drivers to be less careful. In other words, as the shoulder width increases, drivers may gain an unjustified feeling of security.

Sparks (20) describes a project to investigate the influence of highway characteristics on accident rates in Oklahoma. The approach used was to select independent variables thought to be related to accident occurrence and attempt to measure the

amount of correlation each variable has with some form of an accident index. The ultimate goal of this research was to develop one formula that could be applied to all classifications of rural highways and that could be used to predict accidents effectively so that hazardous locations might be identified and correlated prior to accident occurrence. The independent variables that he attempted to correlate with the accident rate were:

1. Surface width
2. Surface type
3. Shoulder width and type
4. Curvature
5. Gradient
6. Stopping sight distance
7. Passing opportunity
8. Hazard rating
9. Surface and shoulder condition

As expected, most of the independent variables had negative correlations with the accident rate. The most surprising aspect of this study was the low correlations that actually existed between the independent variables and the dependent variables. Only 1.91 percent of the variance in the accident rate was explained by the independent variables used in the study. The standard error of the equation was in excess of 5.00, indicating that the equation is practically worthless for predicting accident rates.

Recent research by Mulinazzi and Michael (13), although dealing with urban arterials, produced a series of linear regression models relating accident rates to design characteristics. In this study, twenty-six independent variables were used. One of the conclusions reached was that accident rates increase with increasing numbers of "friction points" per mile (the sum of the number of approaches to the arterial, intersections and driveways).

Another recent study by Dart and Mann (3) examined the relationship of rural highway geometry to accident rates in Louisiana. This study included 246 sections of rural roadway varying in length from 1 to 17 miles. The analysis of these 246 sections, with respect to total accidents, yielded the following hierarchy of importance (all first order interactions):

1. Traffic volume and pavement cross slope
2. Traffic conflicts and traffic volume
3. Lane widths and traffic conflicts
4. Traffic volume and horizontal alignment
5. Shoulder width and horizontal alignment
6. Traffic volume and trucks

The mathematical model tends to indicate that 46 percent of the variation in data is explained by the factors used in the study.

This follows closely to what DeSilva (4) said in 1942. He stated, "The roadway may contribute directly to accidents, or an accident may result from a number of causes which may be traced to an inherent deficiency in the road. Accidents which are directly caused by "defects" in the roads are believed to number

from 3 to 10 percent of all accidents. If we include all accidents in which a fault may have been one of the contributing causes, it is conceivable that 15 to 40 percent of accidents may be traceable directly or indirectly to the roads."

Skewed Distributions

The literature search was continued to determine if work had previously been performed to locate skewed distributions or if any work had been done to correlate speed distributions with accident frequencies. The need for research correlating skewed distributions with accident frequency is brought out in a report prepared for the Minnesota Highway Department by the 3M Company. The authors of this report use this analogy to describe the need for such research, "Monitoring the distribution of vehicle speeds to predict accidents is like taking a patient's temperature or blood pressure. It indicates the health of the patient without having to wait for him to die to know that he was sick." (12, page 37)

The only other work in this field is a study undertaken by the Ohio Highway Department entitled, "The Effects of Speed Zoning on Traffic Operations". (14) This study discusses in length the various methods of speed zoning and the drawbacks of each method. It also compares speed distributions prior to and after speed zoning was initiated. The results indicated that speed zoning did not have a significant effect on speed distributions in all cases.

Factors Affecting Speed Distributions

Several books and studies such as Traffic Engineering by Matson, Smith and Hurd, develop factors which can affect speed distribution curves. (11) These factors include:

1. Desires of the road user
2. Type of vehicle
3. Road design
4. Traffic volume
5. Weather
6. Season
7. Time of day

Previous speed-accident studies tend to be primarily concerned with the correlation of absolute speed and accident frequency. (10,15,16,18) These reports tend to agree on a correlation between accident frequency and absolute speed, but none make any attempt to correlate skewed distributions with accident frequencies.

THE PERCEPTION-SPEED CONCEPT

Analysis of Existing Studies

A close examination of previous studies involving the road geometry-accident occurrence relationship, indicates that no one has been successful in tying down accidents to a particular geometric design. Belmont (1), in his study, concluded that the apparent advantages of wide shoulders are more than offset by the tendency of the driver to be less careful. The statement falls in line with a fairly common occurrence, that being, an increase in accident frequency after a safety improvement has been put in.

What becomes more and more obvious, the further into the literature one goes, is that it is not the obviously dangerous site that will necessarily have the high accident frequency, but rather one that looks safer to the driver than it actually is. If a danger is obvious, the driver will make adequate compensation for it. If it is not, he does not know how much, if any, compensation he should make.

Road geometry is a factor in the occurrence of accidents, however, the way the driver perceives and analyzes the situation ahead of him is what determines if an accident will occur. If a driver is able to analyze the situation properly and make the necessary adjustments in direction and speed, he will probably

not have an accident. If, however, he improperly analyzes the situation ahead, i.e., he believes it is safer than it is, he will likely not make adequate adjustments in his driving and may be "over committed" into an accident. He may also perceive the situation to be more dangerous than it actually is and "over compensate" for it. This could also lead to an accident, in particular a rear end collision, as a person following might be perceiving the situation differently.

The Role of Perception

What exactly is this term perception? The unabridged dictionary gives many choices, but the one best suited to this research is, "the awareness of the elements of the environment through physical sensation". At least two elements are involved in perception:

1. A physical sensation such as vision, hearing or touch
2. An awareness or recognition of what that physical sensation means compared with other physical sensations received by the driver

In the case of vision, it is not just an image on the retina, but a recognition and interpretation of that image that go to make up perception.

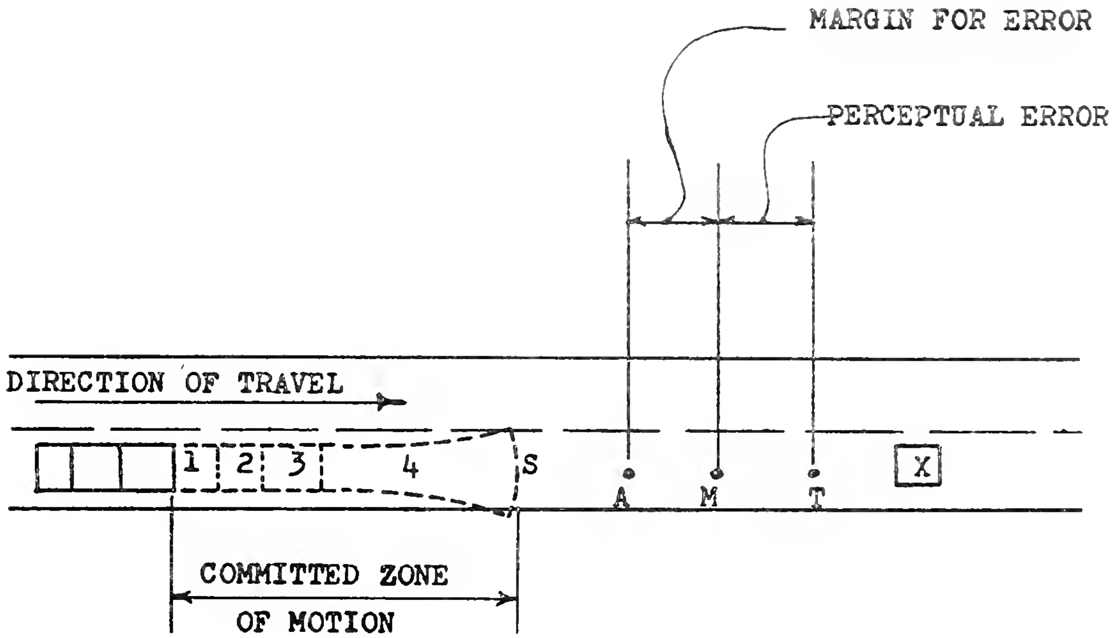
In driving, the chief physical sensation received by the driver is a visual one. Other senses play minor, but in some cases important roles. For the purpose of this concept, it will be considered that the driver gets his information and perceives the hazards ahead visually. He perceives his speed in

relationship to other objects visually by the changing roadway perspective and visually by referring to his speedometer. He makes judgments of the speed and distance of other objects visually.

The Perception Concept

The study of drivers' reactions to a dangerous situation has been previously undertaken by various individuals. The following perception-speed concept is based on these studies and defines the events leading up to an accident by the consideration of a driver's perception and his subsequent reaction to various points and times in space.

Figure number 1 shows the various points and zones to be defined in the development of the perception-speed concept. As a vehicle moves down a road, there is an area of committed motion that lies ahead of it. This motion can be broken down into four distinct zones based on a driver's perception, reaction, and the physical characteristics of the vehicle. Zone 1 represents the distance traveled during the minimum perception time, zone 2 the distance traveled during the minimum decision time, zone 3 the minimum distance traveled during reaction time and zone 4 the minimum committed motion area of the vehicle after the avoidance force (either braking or steering) has been made. Zone 4 out to arc S, represents the minimum stopping distance for the vehicle based on vehicle speed and weight, brake efficiency, coefficient of friction between the roadway and tires and other factors.



LEGEND

X - HAZARD
T - TRUE POINT
M - MENTAL POINT
A - ACTION POINT
S - DISTANCE TO STOP VEHICLE ONCE REACTION HAS TAKEN PLACE

1 - DISTANCE TRAVELED DURING PERCEPTION
2 - DISTANCE TRAVELED DURING MINIMUM DECISION TIME
3 - DISTANCE TRAVELED DURING REACTION TIME

FIGURE 1, PERCEPTION MODEL

On the right of the figure is a box X, which indicates a hazard of some sort. This could be an actual hazard or a potential hazard such as an intersection, a curve, a car ahead starting to slow, etc.

Point T is the true point, the last possible point at which action can be initiated to avoid the hazard. It is the point of no return and is defined by the zone of committed motion and by the laws of physics. Action initiated after point T to avoid the hazard may help in injury reduction, but will not be effective in avoiding the accident completely. Point M is the mental point and is the driver's perception of the true point. This is where the driver believes the point of no return is. Point A is the action point or the point where the driver decides he will actually take action. Points M and A are shown as points for the sake of simplicity, they in fact are probably perceived by the drivers as being areas. Also this model represents just one instant in time, in the dynamic situation, the various points, the committed zone of motion, and the driver's perception of the relationships are changing from second to second.

Taking these defined points we can readily make some generalizations about their placement based on a knowledge of human behavior. As a driver proceeds down a road, he is continuously setting points A and M ahead. At times, the driver may be very conscious of his search for perceptual clues, while at other times, awareness is almost at the subconscious level.

The distance between points T and M is termed perceptual error. The driver's mental point M can be ahead or behind the

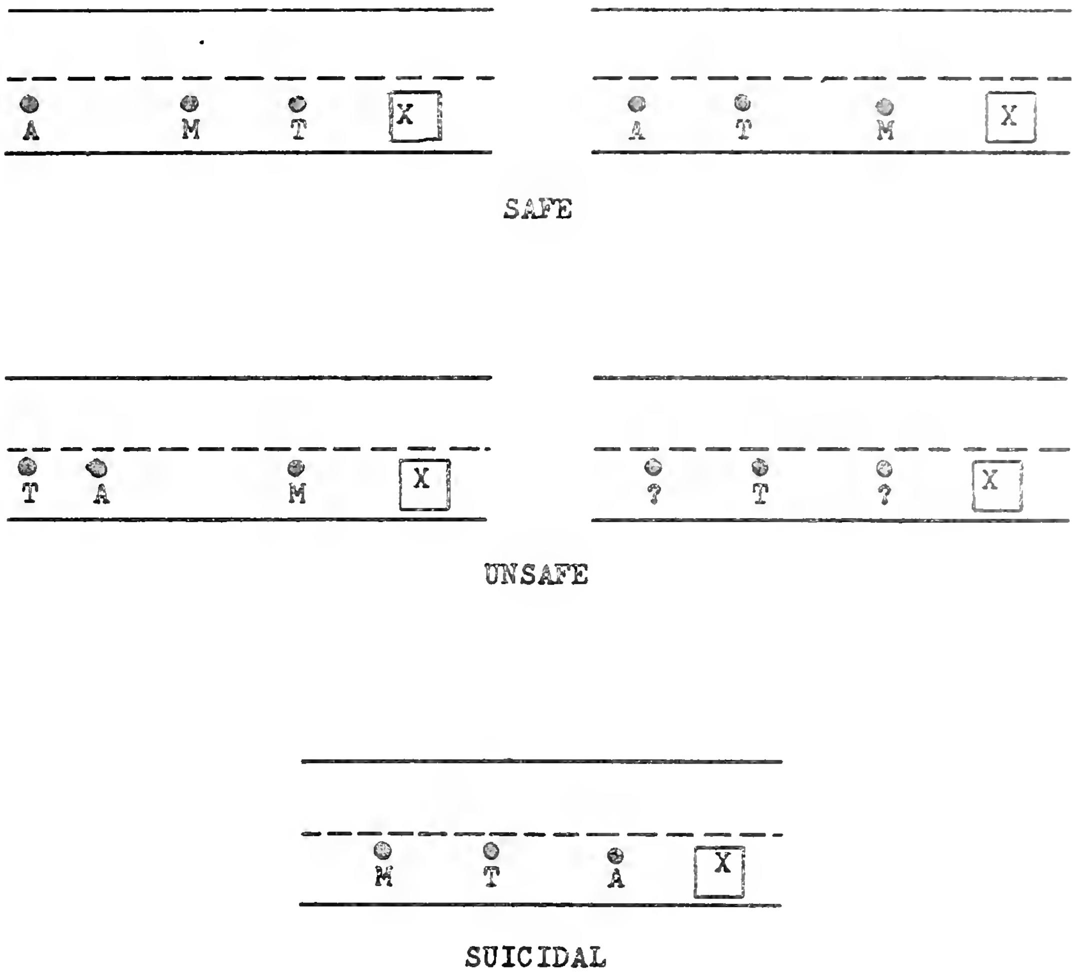
true point T and in the case of no perceptual error, it coincides with point T.

The distance between the mental point M and the action point A is defined as the margin for error. Point A or the action point is always placed by the driver in front of the mental point M. For the driver to place his action point beyond his mental point would indicate that the driver was deliberately looking for an accident.

It is the interaction between points T and M, the perceptual error, and points M and A, margin for error, that will determine if an accident will in fact occur. Three particular situations are shown in Figure 2. As long as the action point A is placed in front of the true point T, no accident will occur. If the driver makes a perceptual mistake and places his mental point beyond the true point, he still may not have an accident if his margin for error is adequate. This is usually the situation if the perceptual error is not large.

The unsafe conditions, as shown in Figure 2, result from the action point being placed beyond the true point. Usually there are three reasons for this situation.

1. The driver allows a small margin for error, i.e., his action point A is close to his mental point M. This situation allows for only very small perceptual errors by the driver.
2. The driver makes such a large perceptual error that even a large margin for error will not prevent an accident.
3. The failure of the driver to set up his mental points



LEGEND

X - HAZARD
T - TRUE POINT
M - MENTAL POINT
A - ACTION POINT
? - POINTS NOT ESTABLISHED

T TO M DISTANCE - PERCEPTUAL ERROR

A TO M DISTANCE - MARGIN FOR ERROR

FIGURE 2, SAFE, UNSAFE OR SUICIDAL SITUATIONS

as he drives along, i.e., the driver may be daydreaming, falling asleep, drunk or passing on a hill or curve.

The third part of Figure 2 shows the suicidal act. In this act the driver places his mental point and then deliberately does not employ his action point until he has passed the mental point.

When considering perception the following points could be drawn:

1. Perceptual error is the proximate cause of most preventable accidents. It is the factor common to most accidents out of a myriad of other factors possible in the chain of cause and effect. It is the human pre-crash factor. Margin for error is not an accident cause, but rather a defense, ameliorating action that does in fact prevent many accidents. There are, of course, sudden cataclysmic failures, such as a heart attack or a blow out, that can cause loss of control. In these special cases perception, as it is being considered in this research, does not play a major role. For the great majority of accidents, however, perceptual error is the cause and the common factor present.
2. This perception concept indicates that accidents can be prevented by increasing the margin for error and by making the perceptual error as small as possible. Increasing the margin for error has been the focus of most accident prevention methods tried to date. The

success of this method to date has been rather questionable. Increasing the margin for error is usually too restrictive for most drivers. Each driver has a built in risk level that is a part of his own personality. Thus, it is not practical to try to get all drivers to drive ultraconservatively all the time. One method that has been tried is to make situations on the road seem more dangerous than they actually are. However, it seems that the driver soon adjusts and compensates for situations that seem unreasonable. For example, a warning sign reading 15 m.p.h. on a curve that can be driven 40 will usually be disregarded.

The Affect of Speed

A driver's speed is one of the most important factors in his visual perception of his situation and the situation in front of him. Speed affects:

1. The margin for error
2. The number of simultaneous decisions
3. The length and width of the field of view (increased speed lengthens and narrows this field)
4. The apparent motion between objects
5. The drivers's alertness
6. Where the driver looks

Too little speed can cause a danger obstacle to the rear of the slow vehicle. It can also reduce the apparent relative motion between objects and backgrounds, thus making speed and

direction judgments more difficult. Too little speed can also affect driver alertness by causing the driver to focus his eye attention closer, where the motion contrast is the greatest. This can create a tendency for the driver to incorrectly perceive fast approaching distant objects. (10)

Too much speed, on the other hand, increases the severity of collisions, the number of simultaneous decisions and creates a tendency to lengthen and narrow the cone of vision. High speed also velocitizes the driver causing objects to blur, making them less detectable and conspicuous.

The research studies correlating accident frequency with speed (14,15,18,21) tend to indicate that speed is inversly related to accident frequency up to about the mean speed. (Fig. 3) Beyond this point it correlates positively. Restating this another way: slower, or higher than mean speeds contribute significantly to accident frequency, while speeds around the mean contribute less to accident frequency. In other words, accident frequency potential appears to increase for those drivers who deviate significantly in either direction from the mean speed.

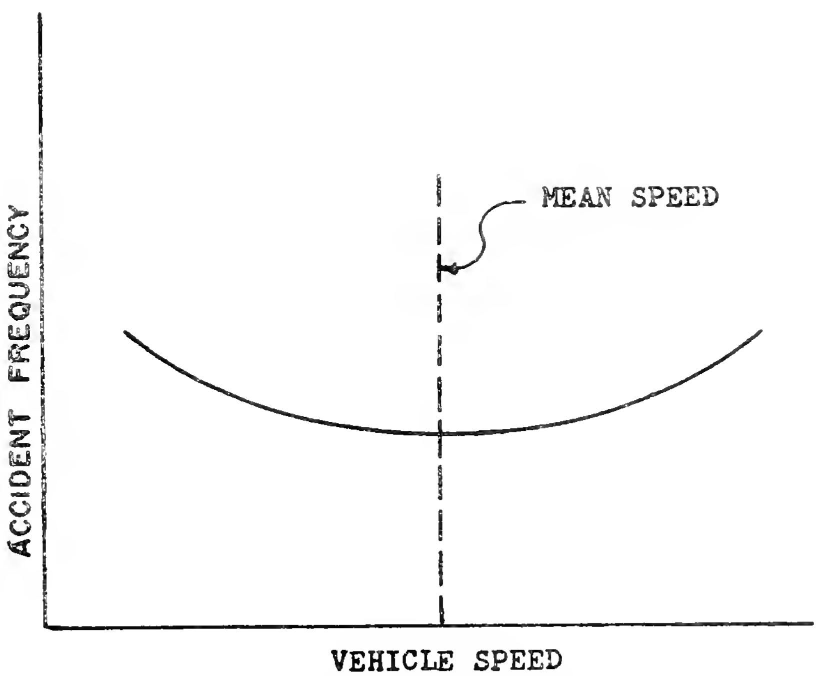


FIGURE 3, ACCIDENT FREQUENCY AS A FUNCTION OF VEHICLE SPEEDS

THEORY & PLAN OF STUDY

Theory

If the perception-speed concept is true, it should be possible to use it to develop a means of predicting where accidents will occur. Consider a particular point on a given stretch of two-lane rural state highway. The laws of probability would tend to indicate that, if given enough measured vehicle speeds, one would expect to find a normal distribution at that point. This normal distribution would be centered about a mean speed. (Fig. 4) The slower the mean speed, the narrower one would expect to find the distribution about the mean. The mean speed would undoubtedly vary from point to point, but on a whole the distributions would remain essentially normal unless some other factor was affecting the situation.

The literature search has indicated that in a situation where all drivers are able to determine and evaluate the local conditions under free flow, the resulting speed distribution would be normal and show no skewness. This can be attributed to each driver choosing a "best" speed based on his individual evaluation of the various factors associated with different speeds. If all drivers were to evaluate these factors in the same way, the resultant speed distribution would be a single value function, i.e., all drivers would drive at the same speed.

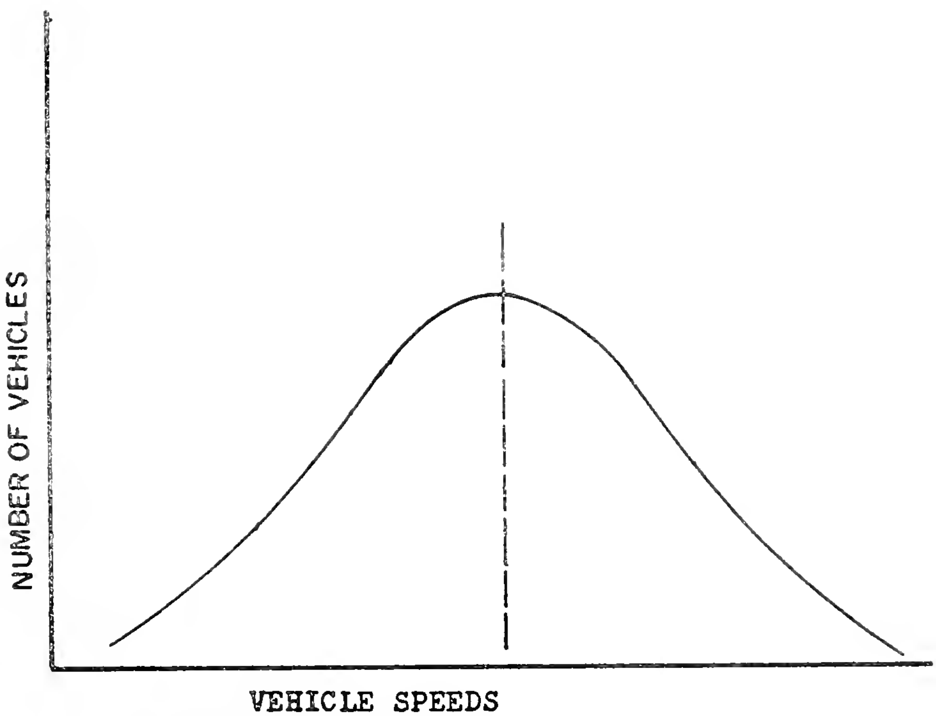


FIGURE 4, NORMAL SPEED DISTRIBUTION

It is a fact that speeds do not approach a single value function, but rather a normal distribution about a mean.

This resultant normal distribution can be attributed to mainly two things. The first is the fact that there are certain factors associated with traveling that cannot be expressed in monetary terms. The factors of comfort, convenience or service are examples of such costs. Since these factors cannot be expressed on the same scale as operational costs, accident costs and time costs (the three costs generally associated with analysis), it is difficult to determine a true total cost of travel. Each driver determines the balance between the comfort, convenience and cost factors on an individual basis. For example, a person who considers time costs to be much greater than operational costs may have a tendency to travel at higher than the mean speed. For most drivers, this balance will put his vehicle speed near the mean speed, however, a small number will deviate significantly from this speed.

The second factor which precludes a single value function is that man is not purely an economic entity, and thus any theory based purely on economics is not realistic. The two factors are related in the sense that it may be these considerations of comfort, convenience, etc., that makes man a social rather than an economic entity.

If the relative value each individual driver places on the different costs of transportation, including the factors of comfort, convenience and service does not change as the drivers enter different sections of the highway, then the distribution

of speeds will not change with location. If the drivers can properly evaluate the variations in these factors with the variations in the situations that they meet, the parameters of the distribution will change, but the shape of the distribution itself will not.

Under free flow conditions, the normal speed distribution in fact does not exist at all points on rural highways. The premise that the variation in distributions, which do occur, is the result of the driver's inability to properly evaluate the situation, is the basis for the hypothesis developed in this thesis. It is hypothesized that:

> Areas of highways exhibiting a skewed speed distribution during free flow conditions, are areas where drivers are having perceptual difficulties and are thus points of high accident potential.

The particular parameter of a distribution that was used in this research is skewness. Skewness is defined by Yule and Kendall as, "the case of frequency distributions that decrease with markedly greater rapidity on one side of the maximum than on the other. A normal curve is one where the distribution on one side of the mean is essentially the mirror image of that on the other side." (23, page 137)

Two possible skews may appear. A skew left would tend to indicate some drivers were perceiving the area to be more dangerous than it actually is, and thus are overcompensating for it. (Fig. 5) A skew right would tend to indicate some drivers are perceiving the area to be safer than it actually is and are not making adequate compensation. (Fig. 6)

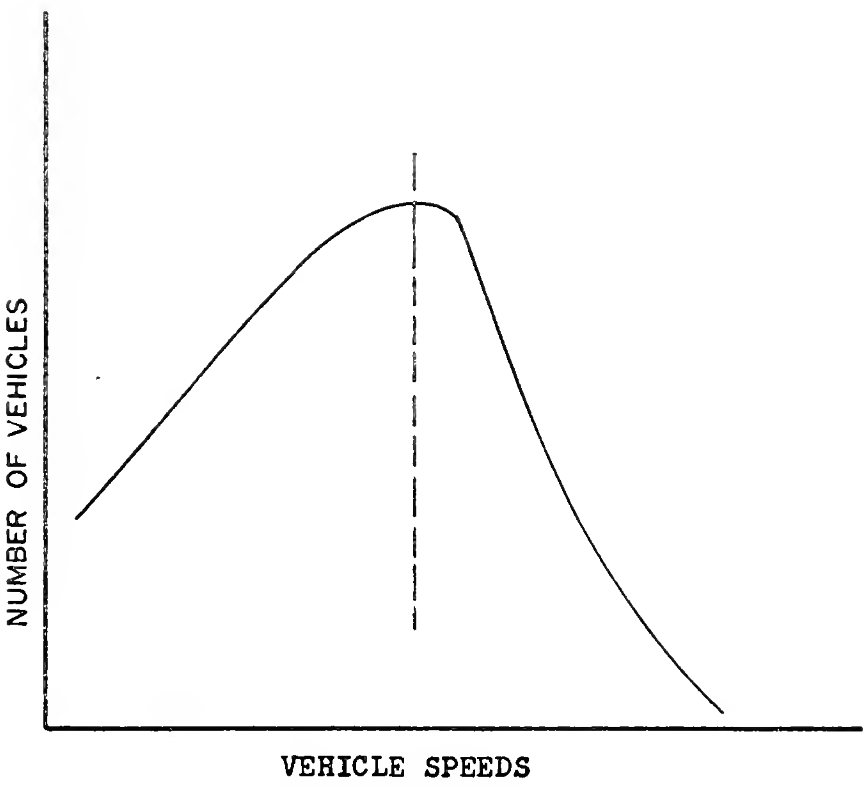


FIGURE 5, NEGATIVE SKEW SPEED DISTRIBUTION

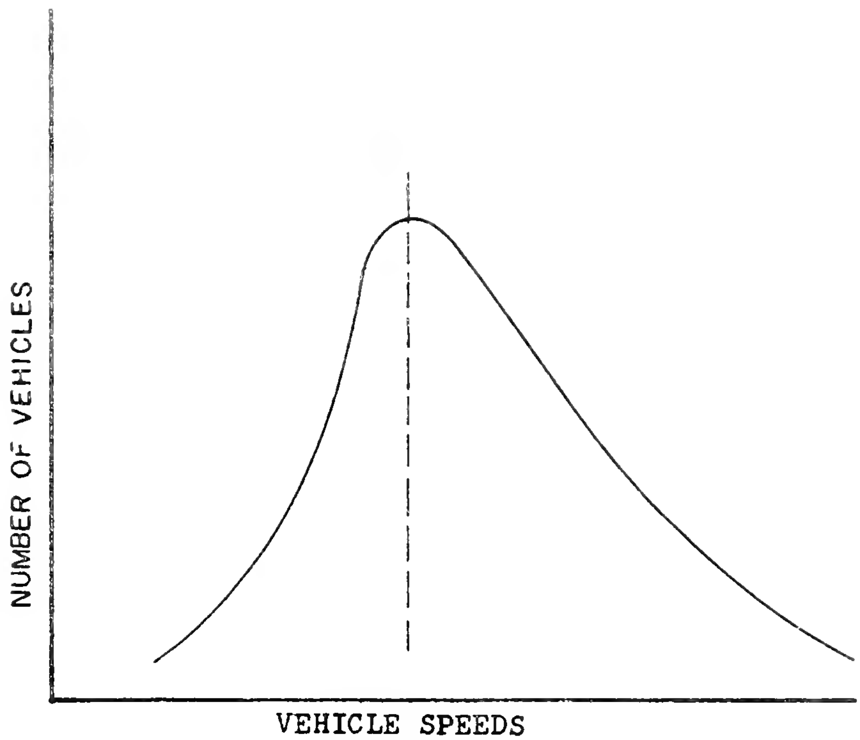


FIGURE 6, POSITIVE SKEW SPEED DISTRIBUTION

Plan of Study

Various research studies have indicated that perceptual difficulties cause many accidents. The basic hypothesis to be tested by this research is that these points of perceptual difficulty and thus points of high accident potential, can be located by a deviation from a normal speed distribution curve.

In order to verify or deny this hypothesis, the following test procedure was devised:

1. Test sites were selected on the basis of their previous accident histories. These sites were divided into high and low accident frequency categories.
2. At each of the selected sites, spot speeds were taken and compiled to get a speed distribution curve for each site.
3. At certain sites, speed data was taken both during the day and at night, and on both sides of the road.
4. The resultant speed distributions for the low accident sites were checked for normalcy to validate the normal speed distribution at most points assumption.
5. All the speed data were correlated with the respective accident data to determine if a correlation between the type of distribution curve and the accident frequency did in fact exist.
6. Day and night conditions were compared to determine if there was a significant deviation in the driving habits of people during the day as compared to night.

7. Directional data were compared to determine if the perceptual difficulty was for only one direction of travel or for both.

PROCEDURE

Study Locations

Because of the presence of numerous two-lane rural highways in Tippecanoe County, and because of their varied alignments and accident histories, all study locations were selected from within the county. Four highways were considered for this research, State Routes 25, 26, 38 and 43.

Accident data for these routes were available through the Indiana State Police Post in West Lafayette. Accident data for 1972 and the first half of 1973 were used in the selection of test sites. Areas with one or no accidents during the past 18 months were considered as low accident areas and those with five or more as high accident areas. This criteria was established following subjective review of all the accident reports for the county. It should be noted that in all cases, the accident occurrence was within a band approximately one quarter mile on either side of the reference location. In addition, the accident histories showed no predominate direction of travel for accident occurrence.

State Route 25 exhibited an unusually high accident frequency history. This could be partly attributed to the alignment of the road which contains numerous horizontal and vertical curves. This constantly changing alignment could be causing

drivers to have perceptual difficulties. Three sites were chosen for study along this route. Five sites were chosen on State Route 38 and two sites were chosen on both State Route 26 and State Route 43. (Fig. 7) All twelve sites were chosen on the basis of their alignment and past accident history. Detailed drawings of each study site are included in the Appendix. Pertinent data concerning the sites are shown in Table 1.

Site number one is located on State Route 26, approximately halfway between the entrance to Heritage Estates Subdivision and County Road 500E. This location is approximately one mile east of the intersection of I-65 and State Route 26. The alignment at this site is level and tangent. The roadway is asphalt with lanes approximately 12 feet wide. The shoulders are unpaved and at places there is up to a 4 inch drop off from the pavement. The posted speed limit at the time of testing was 65 m.p.h. This area has experienced seven accidents during the period from June 1968 to June 1973, and no accidents from January 1972 to June 1973.

Site number two is located on State Route 43, approximately one half mile south of County Road 500S. The alignment at this area is level and tangent. The road surface is asphalt with lanes approximately 12 feet wide. The shoulders are unpaved. Approximately one quarter mile north of the test site exists a small subdivision with several entrance roads. The posted speed limit at the time of testing was 65 m.p.h. The area has had seven accidents during the period from June 1968 to June 1973, and no accidents during the period January 1972 to June 1973.

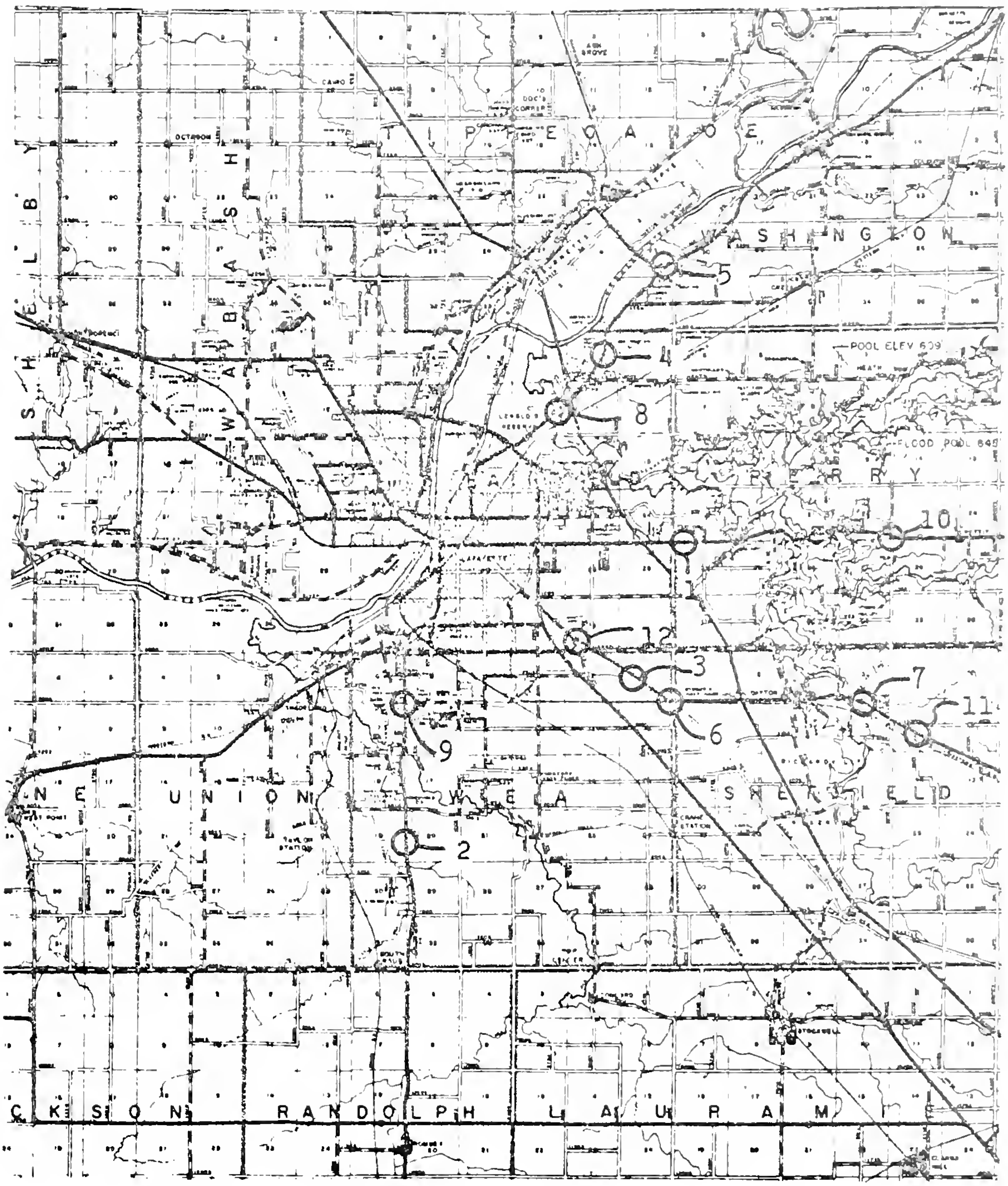


FIGURE 7, MAP OF SITES

TABLE 1

SITE LOCATIONS DATA

SITE	LOCATION	ACCIDENT HISTORY		DATA COLLECTED				ALIGNMENT					POSTED SPEED LIMIT*
		18 MO.	5 YR.	DAY	NIGHT	D1	D2	1	2	3	4	5	
1	SR 26 NEAR CR 500E	0	7	X		X			X	X			65
2	SR 43 NEAR CR 500S	0	7	X		X			X	X			65
3	SR 38 NEAR NEWCASTLE ROAD	1	10	X		X			X		X		55
4	SR 25 BET. CONNIE DR. & CR 300N	12	67	X		X		X				X	60
5	SR 25 NEAR SR 225	8	35	X	X	X		X				X	60
6	SR 38 AT NEWCASTLE ROAD	5	26	X	X	X		X		X			55
7	SR 38 AT HARDING RD.	5	19	X	X	X		X		X			65
** 8	SR 25 NEAR CR 200N	15	51	X	X		X		X	X			55
** 9	SR 43 NEAR CR 300S	6	32	X	X		X		X		X	X	55
**10	SR 26 NEAR CR 900E	1	4	X			X	X		X			55
**11	SR 38 NEAR CR 950E	0	6	X			X	X			X	X	55
**12	SR 38 NEAR ROSS ROAD	1	11	X			X	X		X			50

* AT TIME OF TEST

** SITES ADDED 4-74 (AFTER SPEED LIMIT CHANGE TO 55 M.P.H.)

D1 DATA TAKEN FOR ONE DIRECTION OF TRAVEL

D2 DATA TAKEN FOR BOTH DIRECTIONS OF TRAVEL

ALIGNMENT:

1 - HORIZONTAL CURVE
2 - TANGENT
3 - LEVEL GRADE
4 - UPGRADE
5 - DOWNGRADE

Site number three is located on State Route 38, approximately one half mile northwest of the intersection with Newcastle Road. The roadway alignment through this area is rolling and tangent. The roadway surface is asphalt, with lanes approximately 11 feet wide. Three-foot paved shoulders exist on both sides of the road throughout the test section. The area has had 10 accidents during the years of June 1968 to June 1973, with one accident in the period between January 1972 and June 1973. The posted speed limit at the time of testing was 55 m.p.h.

Site number four is located on State Route 25 between the intersection of County Road 300N and Connie Drive. This particular area is on a downgrade and a horizontal curve. The road surface is asphalt, with lanes approximately 12 feet wide. A new subdivision is developing in the area and deceleration lanes for right hand turns are provided. The posted speed limit through this area at the time of testing was 60 m.p.h. This area has had a high accident history, with 67 accidents recorded during the period between June 1968 and June 1973, with twelve occurring during the last 18 months of this period.

Site number five is located on State Route 25, approximately one quarter mile east of the intersection with State Route 225. The site is on a downgrade and a horizontal curve with reference to the direction of travel tested. The road is asphalt with lanes approximately 12 feet wide. The shoulders are unpaved. The posted speed limit through this area at the time of data collection was 60 m.p.h. The area has a high accident

history, most being induced by vehicles either entering or leaving State Route 225. The area had 35 accidents during the five year accident history search and eight during the eighteen-month history period.

Site number six is at the intersection of State Route 38 and Newcastle Road, southeast of Lafayette. The site is level and on a horizontal curve. Newcastle Road intersects with S.R. 38 in a "T" intersection about midway in the horizontal curve. The roadway is asphalt, with lanes approximately 12 feet wide. The shoulders are paved approximately 3 feet. The posted speed limit at the time of data collection was 55 m.p.h. The location has had twenty-six accidents during the five year study period, with five occurring during the last 18 months of the period. This site is located approximately one half mile southeast of site number three.

Site number seven is located near the intersection of State Route 38 and Harding Road. Harding Road, much like Newcastle Road, intersects State Route 38 in "T" intersection at about the midpoint of the horizontal curve. State Route 38, at the test site, is level and on a horizontal curve. The road surface is asphalt with lanes approximately 10 feet wide. The shoulders are unpaved. The posted speed limit at the time of data collection was 65 m.p.h. There have been 19 accidents at this site over the five year study period with five occurring during the last eighteen months of the period.

Site number eight is near the intersection of State Route 25 and County Road 200N. This particular site is in close

vicinity to the intersection of State Route 25 and I-65. Approximately 100-200 feet northeast of the test intersection, State Route 25 widens out to form the interchange with I-65. The test area is level and tangent except for the widening for the I-65 interchange. The pavement is asphalt transitioning into concrete at the widened portion. There are no paved shoulders along the asphalt section, however, they do exist along the widened section. This section of roadway from west of County Road 200N to east of the I-65 interchange has experienced 51 accidents during the 5 year study period and 15 during the 18 month period.

Site number nine is located near the intersection of State Route 43 and County Road 300S. This area is level and tangent, although there is a horizontal curve approximately 200 feet to the south. The area immediately adjacent to this section of roadway is residential and there are a number of driveway intersections. The roadway is asphalt, approximately 12 feet in width. The shoulders are unpaved. This section of roadway has experienced 32 accidents during the five year study period and 6 during the 18 month period.

Site number ten is near the intersection of State Route 26 and County Road 900E. Through this area, the alignment of State Route 26 is a reverse curve with a short tangent all on a relatively level grade. County Road 900E intersects State Route 26 on the tangent portion between the reverse curves. The roadway through the test area is asphalt, approximately 12 feet wide with no paved shoulders. This area has a low accident history

showing 5 accidents during the study years and 1 accident between January of 1972 and June 1973.

Site number eleven is on State Route 38 near the intersection with County Road 950E. State Route 38 through this area is on a horizontal curve and a level grade. County Road 950E intersects State Route 38 at about midpoint of the horizontal curve. A small residential area is developing to the north of the site. This residential area is producing numerous driveways connecting to State Route 38. The posted speed limit through the section was 55 m.p.h. at the time of testing. The roadway is asphalt, approximately 10 feet in width. The shoulders are unpaved. The area has had 6 accidents during the five year history search and none during the last 18 months of the history.

Site number twelve is near the intersection of Ross Road and State Route 38. When approaching from the west going east, Ross Road angles off to the right forming a "Y" intersection. At that point the alignment of State Route 38 curves off to the left. The area is developed, with a roller rink existing in the triangular portion of the intersection and with new residential development to the north. About one half mile to the west is the entrance to Tippecanoe Mall, K-Mart and other businesses. The roadway through this area is 12 feet wide and asphalt. Three-foot paved shoulders are in existance throughout. The posted speed limit at the time of testing was 50 m.p.h. There have been 11 accidents during the five year accident history used and 1 during the final 18 months of the history.

Test Procedure

The test procedure was designed as a method of determining the relationship that exists between locations of high accident occurrence and the normality of the speed distribution. Since the normality of a distribution is not a variable which can be quantified, but one which can only be classified, the required analysis is a test of differences between classes. The two classes to be used are normal and skewed, as determined at the 95% level by analysis of skewness. The 95% level was chosen because of its use in numerous previous studies. (14,15,16,17)

Several important assumptions need to be stated at this point. The first one is that all factors involving the vehicle and the roadway were assumed to be constant at each test site. Each test site has its own unique characteristics, i.e., roadway alignment and signing. These factors are constant for every vehicle entering the particular test section. By insuring that the factors controlled by the environment such as light, pavement wetness, visability, etc., are relatively constant for all vehicles, the only variable left that determines a vehicle's speed through the area is the driver and his perception of the situation ahead of him. Although the driver's maximum speed is pretty much influenced by the posted speed limit, he will proceed at a speed at which he feels comfortable.

The second assumption deals with the reaction of the driver to a particular situation. It is assumed that a driver will maintain essentially a constant speed while driving down a road. When a particular situation presents itself to the driver, he

will make an appropriate adjustment in his speed. He will then maintain an adjusted speed until he has safely passed the problem area or area of uncertainty. He will then adjust his speed to the original speed at which he was going. (Fig. 8) For the purpose of this research, it is assumed that a driver will maintain essentially a constant speed through the perceptual difficulty area. This area corresponds to the area or band of accidents as previously defined in the Study Locations subsection. Using this assumption, speed data taken anywhere within the accident band should reflect the constant true speed of the driver through the area. The use of speed data outside of the accident band would give variable speeds in either an accelleration or a decelleration transition zone.

Data were collected in the form of vehicular speed observations. Individual speeds of vehicles passing through the test section for sites one through seven were recorded with the use of an Esterline Angus 20-Pen Recorder. (Fig. 9) Speed data for these sites were collected in July and August of 1973. The speed recording equipment is a continuous recording apparatus which is capable of recording the occurrence of twenty events simultaneously. The recording mechanism is electrically operated and the drive mechanism is a mechanical wind up system. The drive mechanism has interchangeable gears to allow the recorder to be used at various drive speeds. For the purposes of this research, a speed of 12 inches/minute, the fastest drive speed without the use of a separate electrical drive, was used. Each of the twenty pens of the recorder is activated by the

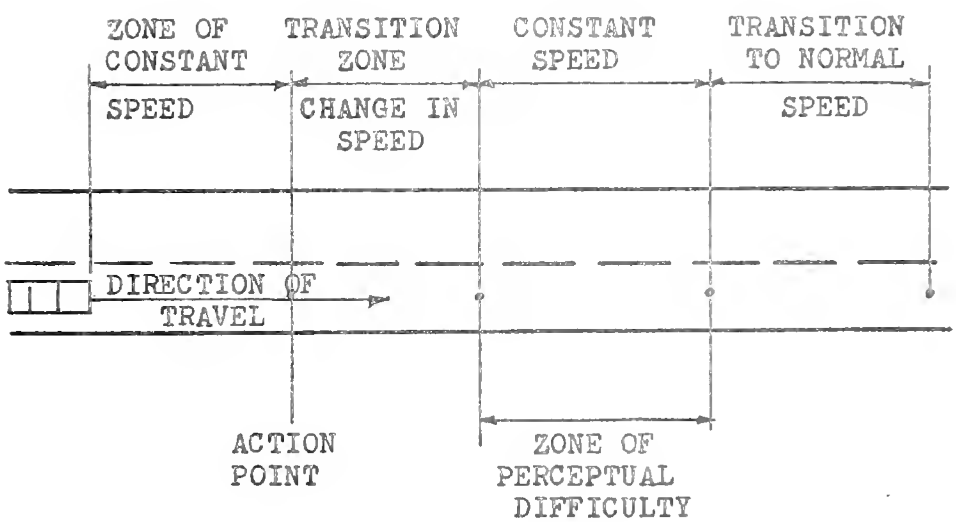


FIGURE 8, DRIVER REACTION TO A ZONE OF PERCEPTUAL DIFFICULTY

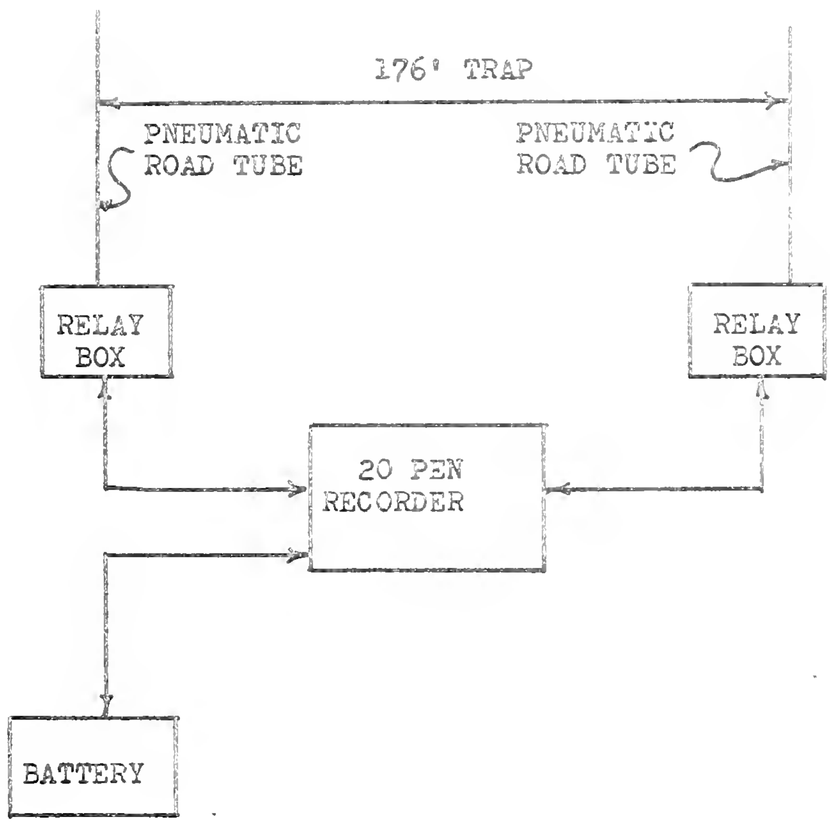


FIGURE 9, TYPICAL EQUIPMENT SET UP

opening and closing of an electrical circuit connected to it. In this research, pneumatic tubes were used as roadway detectors. These tubes were connected to relay boxes which contained a diaphram that opened and closed with the impulse of a car crossing the tubes. This opening and closing of the diaphram in the relay box opened and closed the circuit in the 20-Pen Recorder, causing the actuation of the pens to record the event. One pen was used for a vehicle entering the trap and a second pen was used when the vehicle left the trap. This activity was recorded on the continuous recording paper of the 20-Pen Recorder by two marks along the continuous tracks of the pens. These marks were separated by a distance which is proportioned to the speed of the vehicle going through the trap.

Although the tubes were visible to the approaching motorist, no appreciable reaction by the motorist was noted. Care was taken to insure that all other equipment was hidden so as to minimize the biasness of the sample. It was determined through the literature search that speed movements should be measured within about 3 m.p.h. Since the 20-Pen Recorder was operated at its fastest drive speed, the speed trap was large enough (176 feet) to allow speed measurements within 5 ft./sec. (3.4 m.p.h.)

It has been previously stipulated that only free flow data would be used in the analysis for this research. Since queues form rather frequently on rural state highways, a method was needed to distinguish a vehicle traveling under free flow conditions from one which was being influenced by a preceding vehicle. The 176 foot trap was an equivalent distance of approximately 10

car lengths, which was considered a minimum spacing necessary to maintain free flow, therefore it was decided to eliminate any data of a vehicle that entered the trap prior to the preceding vehicle leaving the trap. With this criteria, only the speed of the first car in a queue was used as data. Any other data from cars in the queue were not used. In some instances, a vehicle entered the trap from a nearby driveway or roadway and had not yet reached its free flow speed. These vehicles were noted on the recording paper and the data from them was not used.

Data were collected from three study sites (five, six & seven) during nighttime hours. These data were compared to the data acquired during daytime hours to see if a significant difference in the distribution had occurred.

During the month of April in 1974, additonal sites were selected and data collected. Unlike the data collection method for sites one through seven, the data for the new sites, eight through twelve, were collected using a radar unit. Radar measures vehicle speeds using what is known as the "Doppler Effect", that is the measurement of the difference between a wave length emitted from the apparatus as compared to the wave length received when reflected back off of a passing vehicle. This method is accurate in measuring vehicle speeds to the nearest one mile per hour, slightly better than obtainable using the 20-Pen Recorder equipment. The radar equipment was also considerably easier to set up and easier to screen from detection. The one problem area was the elimination of data from vehicles in a queue. With the 20-Pen Recorder, this was a fairly easy

matter. With the radar, this elimination was made visually on a judgment basis. Upon watching the vehicle stream for a small period of time, this judgment decision became considerably easier to make. Data were collected at site eight and nine during nighttime hours and at all sites in both direction of travel.

Statistical Analysis

The collection and compilation of data can be a useless task unless meaningful tests are applied to insure the significance of the data. This program of tests can also give indications if sufficient and complete data are present and what additional data is necessary.

The first statistical test necessary was one to insure that the sample size was adequate to be statistically significant. Walpole and Meyers state if the sample mean $\bar{X}$ is used as an estimate of the population mean μ , we can be $(1-\alpha)$ 100% confident that the error will be less than a specified amount e, when the sample size is given by: (12)

$$n = \left[\frac{Z_{\alpha/2}\,\sigma}{e}\right]^2$$

where Z is a normal random variable with mean zero and variance one and σ is the standard deviation of the population.

For this particular test, and for all further tests, a 95% confidence limit was used. The value of "e" was selected to be 2.5 ft./sec., which is one half of the 5 ft./sec. interval used to group the data. Walpole and Meyers state that the sample

standard deviation "S" can be used as an estimate of the population standard deviation if the sample size is equal or greater than 30. (12)

Analysis of a set of trial data indicated values of the sample standard deviation to be around 9 ft./sec., therefore it was assumed that the maximum standard deviation for all test sites would not exceed 10 ft./sec. Using this value along with the values based on previous assumptions, the minimum sample size becomes:

$$n = \frac{(1.96)\ (10)^2}{2.5} = 7.84^2$$

$$n = 61.46, \text{ say } 62$$

Following the determination of the minimum sample size, all sites were tested and the data obtained were compiled to find the values of the sample mean $\overline{X}$ and the standard deviation S. Once these values were determined, it was necessary to classify the speed distribution curves of each site according to the amount of skewness each one exhibited. Skewness can be defined as the departure of the frequency-distribution from symmetry.

A measure of the amount of skewness in a population is given by the average value of $(x - \mu)^3$ taken over the entire population. This quantity is called the third moment about the mean. If low values of x are bunched close to the mean μ, but high values extend far above the mean, this indicator will be positive since the large positive contributions of $(x - \mu)^3$, when x exceeds μ, will predominate over the smaller negative contributions of $(x - \mu)^3$, when x is less than μ. Populations

with negative skewness in which the lower tail is the extended one, are also encountered. In order to make this measure independent of the scale on which the data is recorded, it is divided by σ^3. The resultant of this manipulation is called the coefficient of skewness. Mathematically this is given by:

$$C.S. = m_3/(m_2 \sqrt{m_2})$$

where $m_3 = \sum (x - \bar{x})^3/n$

and $m_2 = \sum (x - \bar{x})^2/n$

The values of this coefficient can vary between -1 and +1. A value of zero indicates symmetry and thus no skewness of the distribution. The greater the deviation from zero, either in the positive or negative direction, the greater the amount of skewness the frequency distribution curve exhibits.

ANALYSIS OF DATA

The overall plan for the analysis of data is as follows:

1. Determine the minimum size of the sample to give statistically significant results. This was accomplished in the previous section.
2. Calculate the speed parameters for each test site (mean speed = $\bar{X}$, standard deviation = S, coefficient of skewness = C.S.).
3. Verify the use of .100 as the boundary point between normal distributions and non-normal or skewed distributions.
4. Compare day and night data at the sites where both were taken to determine if there is a significant change in the coefficient of skewness.
5. Compare directional data to determine if there is any significant change in the coefficient of skewness dependent on the direction of travel of the vehicle.
6. Compare the average number of accidents in areas exhibiting normal distributions, as measured by the coefficient of skewness, with the average number occurring in areas exhibiting skewed distributions.
7. Examine the site pair (site 3 and 6) to determine if a

change in the frequency-distribution had occurred between these two sites.

The minimum sample size of the analysis plan was calculated in the previous section. The minimum size for a sample with a 95 percent confidence interval, a standard deviation of 10 ft./sec. and an error factor of 2.5 ft./sec., was found to be 62.

Once all of the data were collected, the parameters sample mean ($\bar{X}$), sample deviation (S), and coefficient of skewness (C.S.) were calculated. A summary of this data is included as Table 3 and an individual analysis of each site is included in the Appendix. For all test sites, the value of S did not exceed 10, thus the assumption that the minimum sample size as defined in the previous sections was correct.

Determination of the Boundary Point Separating Normal from Non-Normal or Skewed Distributions

An examination of the accident histories and the respective coefficients of skewness for each site seemed to indicate that the sites could be logically classified into two groups. The sites that showed low accident histories tended to have coefficients of skewness between 0 and $\pm$.099 and those with high accident histories greater than $\pm$.100. For the purposes of this research, it was assumed that a skew between 0 and $\pm$.099 would indicate a normal distribution, while a skew equal to or greater than $\pm$.100 would indicate a non-normal or skewed distribution.

In order to test the validity of this assumption, the Mann-Whitney or U-test was used. (5, page 296) This test is used to

compare means of small samples in which all of that data does not come from normal distributions or have equal standard deviations. In order to perform the U-test, which is essentially based on a sum of the ranks, it is first necessary to rank all of the measurements jointly, that is, as if they were one sample. Since it is the amount of skewness, and not the direction of skewness that is of concern here, the absolute value of the skews was used.

TABLE 2
RANKED COEFFICIENTS OF SKEWNESS

C.S.	.001	.003	.027	.031	.037	.043
RANK	1	2	3	4	5	6
C.S.	.064	.084	.093	.123	.123	.194
RANK	7	8	9	10.5	10.5	12
C.S.	.216	.217	.229	.236	.293	.300
RANK	13	14	15	16	17	18
C.S.	.313	.331	.345	.469		
RANK	19	20	21	22		

(For the purposes of identification, those coefficients corresponding to low accident rates are underlined.)

The hypothesis that is to be tested is that both samples come from the same population or from equal populations. If this is true, it stands to reason that average ranks for the two samples should be more or less the same.

The mean of the ranks of this first sample or the low accident area group is:

$$1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9/9 = 45/9 = 5$$

The mean of the ranks of the second sample or the high accident area group is:

TABLE 3
INDIVIDUAL SITE PARAMETERS

SITE	NO. OBSERVATIONS	$\bar{X}$ (ft./sec.)	S	C.S.	DISTRIBUTION
1 Day	188	75.13	8.620	+.084	Normal
2 Day	161	84.91	9.065	+.064	Normal
3 Day	147	75.24	7.456	-.093	Normal
4 Day	106	68.16	7.538	+.236	Skewed
5 Day	115	76.48	8.376	-.123	Skewed
5 Night	126	71.78	8.589	-.229	Skewed
6 Day	120	69.00	8.215	+.217	Skewed
6 Night	115	68.43	7.846	+.331	Skewed
7 Day	96	77.65	8.704	-.123	Skewed
7 Night	93	77.42	8.489	-.216	Skewed
8 Day (D1)*	91	67.53	8.379	+.194	Skewed
8 Day (D2)**	92	67.44	8.337	+.293	Skewed
8 Night (D1)	100	68.70	8.635	+.469	Skewed
9 Day (D1)	92	67.77	7.857	+.313	Skewed
9 Day (D2)	99	67.32	7.189	+.345	Skewed
9 Night (D2)	101	67.47	7.369	+.300	Skewed
10 Day (D1)	90	67.94	7.107	-.027	Normal
10 Day (D2)	108	66.99	7.262	+.037	Normal
11 Day (D1)	106	67.26	7.626	+.001	Normal
11 Day (D2)	95	66.84	7.332	-.003	Normal
12 Day (D1)	123	70.04	8.211	+.031	Normal
12 Day (D2)	115	69.70	8.005	-.043	Normal

* D1 Indicates vehicle travel direction toward Lafayette.

** D2 Indicates vehicle travel away from Lafayette

$10.5 + 10.5 + 12 + 13 + 14 + 15 + 16 + 17 + 18 + 19 + 20$
$+ 21 + 22/13 = 16$

If the mean of one population is considerably higher than that of the other, the sample from that population is apt to occupy the higher ranks. The question is, is there a significant difference between the means of these sums?

The decision to use ranked sums instead of average ranks may be based on the statistic:

$$U = n_1 \; n_2 + \frac{n_1 \; (n_1 + 1)}{2} - R_1$$

where n_1 and n_2 are the sizes of the samples and R_1 is the sum of the ranks obtained for the first sample.

$$U = (9) \; (13) + \frac{9 \times 10}{2} - 45$$

$$U = 117 + 45 - 45$$

$$U = 117$$

Assuming that the arrangement of the samples on which R_1, the rank sum for the first sample is based, is random, the sampling distribution of U has a mean $\mu_U = n_1 \; n_2/2$ and a standard deviation $\sigma_U = \sqrt{\frac{n_1 \; n_2 \; (n_1 + n_2 + 1)}{12}}$

Furthermore if n_1 and n_2 are both greater than 8, the sampling distribution of U can be closely approximated with a normal curve. Using a level of significance of 0.05, the hypothesis that the two samples came from equal populations can be tested by:

$$Z = \frac{U - \mu_U}{\sigma_U}$$

If $Z < -1.96$ or $Z > 1.96$; we can reject the hypothesis

while if $-1.96 \leq Z \leq +1.96$, we can accept the hypothesis.

$$\mu_0 = 58.5$$

$$\sigma = 3.4156$$

$$Z = \frac{117 - 58.5}{3.4156} = 17.127298$$

$17.127 > 1.96$, thus we can reject the hypothesis that the two samples, that with low accident histories and that with high accident histories, come from the same population. Based on this calculation, the use of .100 as the boundary between normal and non-normal distributions is justified.

Comparison of Coefficients of Skewness for Day and Night Conditions

It is hypothesized that the coefficient of skewness along a particular section of roadway will not change significantly from daylight to nighttime conditions. The average or mean speed may change, but the overall shape of the curve will remain essentially the same.

For this test, data from sites 5, 6, 7, 8 and 9 were used. These five sites had vehicle speeds taken both during the day and at night. Examination of the data indicates that the mean speed does change somewhat. This change ranged from an increase of 0.17 ft./sec. and 0.15 ft./sec. respectively at sites 8 and 9, to a decrease ranging from 0.23 ft./sec. at site 7, to 4.70 ft./sec. at site 5. (See Table 4) The other portion of the hypothesis was tested to determine if there was a significant change in the skewness of the curves as defined by the coefficients of skewness.

TABLE 4
CHANGE IN MEAN SPEED BETWEEN DAY AND NIGHTTIME CONDITIONS

SITE	MEAN SPEED DAY	MEAN SPEED NIGHT	DIFFERENCE MEAN SPEEDS
5	76.48	71.78	-4.70
6	69.00	68.43	-0.57
7	77.65	77.42	-0.23
8	67.53	68.70	+0.17
9	67.32	67.47	+0.15

Since the size of the sample is small, an appropriate method of estimating means would be with the use of the Gosset "Student -t" distribution. Since the coefficients of skewness measured were dependent on the same factors for both the day and nighttime conditions, an appropriate method of determining significance between the sets of data would be with the use of a paired difference test. The calculations and assumptions for this test are shown in Table 5. The results tend to indicate that the data is on the border line between accepting or rejecting the hypothesis that there is no significant difference between the sum of the means at the 95 percent confidence limit.

A close examination of the data used in this test tends to indicate that one set of data, that for site number eight, is considerably different from the remaining sites. This set of data seems to indicate that there is a considerable change in the amount of skew between the day and night data. This would appear to indicate that the light conditions would have a direct bearing on how a driver approaching this section of roadway would perceive the roadway. If this assumption is correct, more accidents should be occurring at this test site at night than during the day. The accident data as presented in Table 6 seems to fortify this position at that site. At this site a total of 51 accidents have occurred during the five year study period. Of these 51 accidents, 35 or over two thirds of all the accidents occurred during the hours of darkness. An examination of the accident data for the remaining four sites tends to reflect that the accident history was not substantially different during day and night conditions although all sites with a difference in C.S. of > $\pm$ .09 did have more night accidents.

TABLE 5
COMPARISONS OF COEFFICIENTS OF SKEWNESS
FOR DAY AND NIGHT CONDITIONS

SITE	DAY C.S.	NIGHT C.S.	DIFFERENCE*
5	-.123	-.228	+.105
6	+.217	+.332	+.115
7	-.123	-.216	+.093
8	+.194	+.469	+.275
9	+.345	+.300	-.045

*The difference reflects an absolute difference in the skew using the day C.S. as the base, i.e., an increase in skew in either the positive or negative direction was given a positive sign while a decrease in the skew was given a negative sign.

H: $\mu = 0$

A: $\mu \neq 0$

	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$
	+.105	-.004	.000016
	+.115	+.006	.000036
	+.093	-.016	.000256
	+.275	+.166	.027556
	-.045	-.154	.023716
$\sum$	+.543		.05158

$\bar{X} = .543/5 = .109$

$S = \sqrt{\frac{.05158}{4}} = .1135561$

$t = \frac{.109 - 0}{.1135561} \cdot \sqrt{5} = 2.146$

$t = 2.146$ $\qquad t_{.05} = 2.132$ for D.F. = 4

TABLE 6
FIVE YEAR ACCIDENT DATA, DAY AND NIGHT

SITE	DAY	NIGHT	TOTAL
5	16	19	35
6	12	14	26
7	8	11	19
8	16	35	51
9	16	16	32

Retesting the data using the four remaining sites indicates that there was no significant difference between the mean of the coefficient of skewness of the day data as compared to the night data. (See Table 7)

What the results of these tests tend to imply is:

1. In a situation where there appears to be a considerable variation between the day and night coefficients of skewness, the perception of the driver may be significantly different dependent on the lighting conditions. In these cases, one would expect to find a higher accident rate during nighttime hours than during daytime hours.

Furthermore, the relationship between the change in the C.S. of the speed distribution for day and night conditions and accidents may have possibilities as a detection tool for high nighttime accident locations. More data, however, is necessary to draw further conclusions.

Comparison of Coefficients of Skewness Based on Travel Direction

It was further hypothesized that the coefficient of skewness should not vary significantly with respect to the direction of travel of the vehicle. There should also be little variation in the average or mean speed. There may be exceptions to this hypothesis, most likely in areas where the topography and alignment restrict the view of the road for the driver in one direction, but not in the other. An example might be when the driver in one direction approaches a blind curve. In the case of this type of exception, one would expect to

TABLE 7
COMPARISONS OF COEFFICIENTS OF SKEWNESS
FOR DAY AND NIGHT CONDITIONS

SITE	DAY C.S.	NIGHT C.S.	DIFFERENCE*
5	-.123	-.228	+.105
6	+.217	+.332	+.115
7	-.123	-.216	+.093
9	+.345	+.300	-.045

*The difference reflects an absolute difference in the skew using the day C.S. as the base, i.e., an increase in skew in either the positive or negative direction was given a positive sign while a decrease in the skew was given a negative sign.

H: $\mu = 0$

A: $\mu \neq 0$ D.F. = 3 $t_{.05} = 2.353$

	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$
	+.105	+.038	.001444
	+.115	+.048	.002304
	+.093	+.026	.000676
	-.045	-.112	.012544
$\sum$	+.268		.016968

$\bar{X} = .067$

$$S = \sqrt{\frac{.016968}{3}} = .0752063$$

$$t = \frac{.067}{.0752063} \cdot \sqrt{4}$$

$t = 1.78$

$-2.353 \leq 1.78 \leq +2.353$

ACCEPT HYPOTHESIS

find a marked difference in the respective coefficients of skewness. All test sites used in this research had unrestricted views of the roadway from both directions, thus the hypothesis as presented should be true.

For this test, data from sites 8, 9, 10, 11 and 12 was used. Direction D1 is defined as that approaching Lafayette and D2 as that leaving the Lafayette area. At these five sites, test data was taken for vehicles traveling in both directions. An examination of the data indicates that there is no significant change in the mean speed based on direction of travel. The change ranged between .95 ft./sec. at site ten to .080 ft./sec. at site eight. (See Table 8) The other portion of the hypothesis was tested to determine if there was a significant change in the skewness of curves as defined by the coefficients of skewness. The calculations for this test are shown in Table 9.

TABLE 8
CHANGE IN MEAN SPEED BASED ON
DIRECTION OF TRAVEL OF VEHICLE

SITE	MEAN SPEED (ft./sec.) DIRECTION 1*	MEAN SPEED (ft./sec.) DIRECTION 2**	DIFFERENCE IN MEAN SPEEDS
8	67.53	67.45	.08
9	67.77	67.32	.45
10	67.94	66.99	.95
11	67.26	66.84	.42
12	70.04	69.70	.34

* Direction 1 refers to vehicles approaching Lafayette.
** Direction 2 refers to vehicles traveling away from Lafayette.

TABLE 9
COMPARISON OF COEFFICIENTS OF SKEWNESS
FOR DIFFERENT VEHICLE DIRECTIONS

SITE	DIRECTION 1 (D1)	DIRECTION 2 (D2)	DIFFERENCE*
8	+.194	+.293	+.099
9	+.313	+.345	+.032
10	-.027	+.037	-.064
11	+.001	-.003	-.004
12	+.031	-.043	-.074

*The difference reflects an absolute difference in the skew using direction 1 (D1) as the base, i.e., an increase in skew in either the positive or negative direction from the base was given a positive sign, while a decrease in the skew was given a negative sign.

H: $\mu = 0$

A: $\mu \neq 0$ D.F. = 4 $t_{.05} = 2.132$

X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$
+.099	+.101	.010201
+.032	+.034	.001156
-.064	-.062	.003844
-.004	-.002	.000004
-.074	-.072	.005184
$\sum$ -.011		.020389

$\bar{X} = -.002$

$$S = \sqrt{\frac{.020389}{4}} = .0713946$$

$$t = \frac{-.011}{.0713946} \cdot \sqrt{5} = -.3445$$

$$-2.132 \leq -.3445 \leq +2.132$$

THUS ACCEPT HYPOTHESIS

The results of this test indicate that one could be 95 percent certain that there is no significant difference between the mean of the coefficients of skewness for the sites with respect to the direction of travel of the vehicle throughout the test section.

This analysis substantiates the hypothesis that although the parameters of mean speed and sample standard deviations may vary slightly based on direction of travel of the vehicle, the corresponding coefficients of skewness are not significantly different. What this implies is that if the driver has a relatively unobstructed view of the road, he should be perceiving the road the same way irregardless of his direction of travel.

Comparison of Number of Accidents Occurring at Sites with Normal and Skewed Distributions

This portion of the analysis compares the accident frequency of the sites with normal distributions with the accident frequency of those sites having skewed distributions. Previous calculations in this research have defined a coefficient of skewness of .100 as being the boundary between normal and skewed distributions. In addition, it has been found that if the accident data between day and night conditions was approximately even, that we could be 95 percent confident that there was no significant difference in the coefficient of skewness for the night as compared to the day data. Using these findings, data for all but site eight was used with a value of coefficient of skewness of .100 differentiating between a normal or a skewed

curve. Since the number of accidents occurring in any specified region during any specific time interval are independent of those occurring in any other disjoint time interval or region of space and since the probablility of an accident occurring during a very short time interval is proportional to the length of the time interval and not on the number of accidents occurring outside the time interval, a Poisson experiment was used to make the comparison. (22, page 96) The probability distribution of the Poisson random variable X representing the average number of accidents occurring in a given time interval is:

$$p\ (X\ ;\ \mu) = \frac{e^{-\mu}\ \mu^{X}}{X!} \qquad X = 0,\ 1,\ 2\ \ldots\ldots\ldots$$

where μ is the average number of accidents occurring in the given time interval and $e = 2.71828\ldots\ldots$

The average number of accidents occurring in sites exhibiting normal distributions is 7.5 while the average number of accidents in sites exhibiting skewed distributions is 35.8. (Table 10) Using the Poisson experiment technique, the probability of an average 35.8 accidents occurring at sites where an average of 7.5 accidents have occurred can be given by:

$$p\ (35.8;\ 7.5) = \frac{e^{-7.5}\ 7.5^{35.8}}{35.8!}$$

$$= \sum_{x=0}^{35.8} p\ (x;\ 7.5) - \sum_{x=0}^{34.8} p\ (x;\ 4)$$

$$\rightarrow 0$$

Thus there is very little probability that an average of 35.8 accidents can occur within sites that have exhibited an average of 7.5 accidents.

TABLE 10
ACCIDENT DATA DISTRIBUTION CORRELATION (5 YR. DATA)

NORMAL DISTRIBUTIONS

C.S. $<$ .100

SITE	NO. ACCIDENTS
1	7
2	7
3	10
10	4
11	6
12	11

$\bar{X} = 45/6 = 7.5$

SKEWED DISTRIBUTIONS

C.S. $\geq$ .100

SITE	NO. ACCIDENTS
4	67
5	35
6	26
7	19
9	32

$\bar{X} = 179/5 = 35.8$

Comparison of Sites Three and Six

The final comparison to be made was a study involving the site pair, sites 3 and 6. These two sites are located on S.R. 38 in the vicinity of the intersection of Newcastle Road. Site 3 is located about one half mile northwest of Newcastle Road and site 6 is located in the vicinity of Newcastle Road. Site number 3 was a level, straight section of roadway that had one accident during the preceding eighteen months. Site number 6 is on the curve approaching the "T" intersection with Newcastle Road. This site has had five accidents during the past eighteen months. The coefficient of skewness for site 3 is -.093 and the coefficient of skewness for site 6 is +.217. This data tends to indicate that almost all drivers are perceiving the roadway quite correctly at site 3, while some are perceiving it incorrectly at site 6. It is this perceptual difficulty that leads to more accidents as is true for site 6.

RESULTS AND FINDINGS

The hypothesis tested by this research was: areas of perceptual difficulty (i.e., areas of high accident potential) can be located by a deviation from a normal speed distribution. It was assumed that areas with high accident histories had perceptual difficulties and it was these perceptual difficulties that were the cause of many of the accidents.

This research was successful in correlating areas with high accident histories with non-normal or skewed distributions and areas of low accident histories with normal speed distribution frequencies. The third moment about the mean proved to be an effective measure of the amount of skewness in each speed distribution. A value of .100 of the coefficient of skewness was tested and was found to be a logical break point between normal and non-normal distributions.

This research supports the hypothesis that although the individual parameters may vary when studying day and night data for the same site, the overall shape of the speed frequency distribution curve will not significantly change unless there exists a perceptual difficulty under one lighting condition that is not found under another. In such a case, one would expect to find a significant difference in the shape of the distribution curve in addition to differences

in the site parameters. One such site was found among the test sites. This site showed a large increase in the coefficient of skewness when comparing night data against day data. The accident data at this site also reflected an increase in accident frequency during the hours of darkness. This research did not explore this situation any further; however, the logic of the conclusion could be verified by testing other sites with the characteristics of the above mentioned one.

This research also verified the hypothesis that although individual site parameters may vary when taking speed data for both directions of travel at a site, the overall shape of the speed frequency distribution curve will not significantly change. This hypothesis was, of course, predicated on the assumption that the driver had similar views of the site from either direction. Had there been a "blind spot or blind curve" as viewed from one direction as opposed to the other, the hypothesis would not be valid. If the view of the site is similar, the accident data should not show any directional bias. If such a bias is found, it could, along with a significant change in the shape of the speed distribution curve, indicate a perceptual difficulty in one direction, but not in the other. In this research, no such sites were included.

The small study which compared the data from sites three and six tended to indicate that the speed distribution curve does change in shape as drivers move from a site with no

perceptual difficulties to one that appears to have a perceptual difficulty. This change in shape indicates an uncertainty on the part of some drivers and it is this uncertainty that may result in accidents.

The findings are summarized as follows:

1. There is a direct correlation between the coefficient of skewness as measured by the third moment about the mean of a speed frequency distribution curve and the previous accident history of that area. A value of .100 for the coefficient of skewness is a logical point to separate normal from non-normal distributions.
2. If the accident histories along a particular length of road are essentially the same for day and night, and for each direction, then there will be no significant difference in the coefficients of skewness for day and night and directional speed data.
3. A driver's perception accuracy of the roadway may change as he proceeds down the road. This change in accuracy of perception can be measured by changes in the coefficient of skewness of the speed distribution of vehicles at locations along the roadway.

SUGGESTIONS FOR ADDITIONAL RESEARCH

During the conduct of this research, several suggestions for additional research have been noted. The more important of these are:

1. A verification of the assumption of a driver maintaining a constant speed through the area of the perceptual difficulty.
2. A comparison of the frequency distribution curves for sites exhibiting a large change in accident frequency from either day to night conditions, or based on the direction of travel. It was concluded by logical inference from this research that such sites should show significant differences in coefficients of skewness based on light conditions or direction of travel.
3. A comparison of speed frequency distribution curves at a high accident site using different methods of warning motorists of the perceptual problem.

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APPENDIX

SITE DETAIL FIGURES AND SPEED DATA TABLES

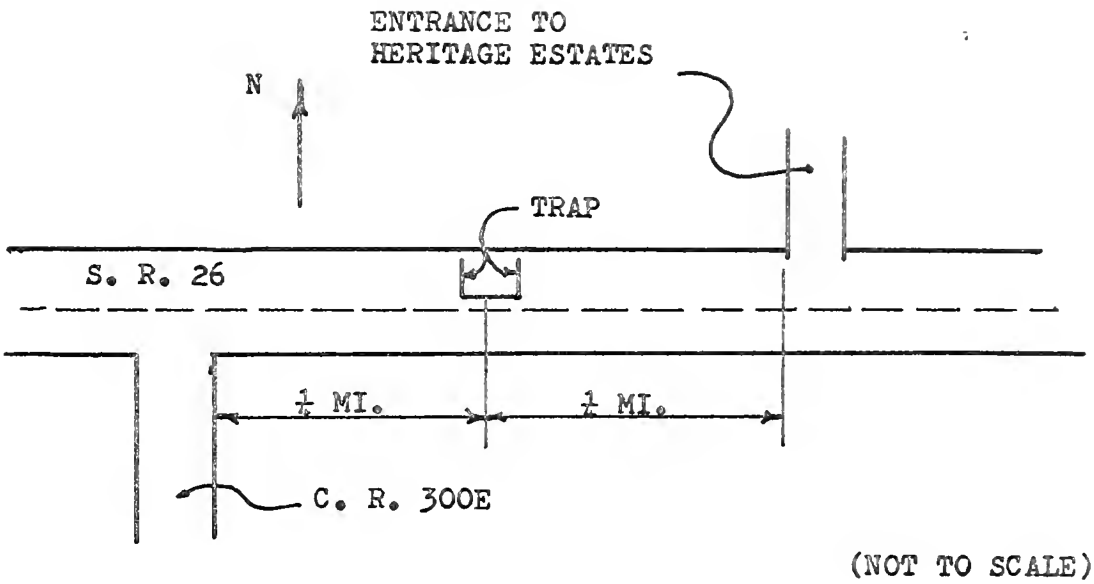


FIGURE 10, SITE NUMBER ONE

TABLE 11
SITE NUMBER ONE DATA

X_i (ft./sec.)	NO. OBS.
55	4
60	7
65	25
70	35
75	46
80	32
85	25
90	7
95	6

$\bar{X}_i$ = 75.13 ft./sec.
S = 8.620 ft./sec.
C.S. = .084

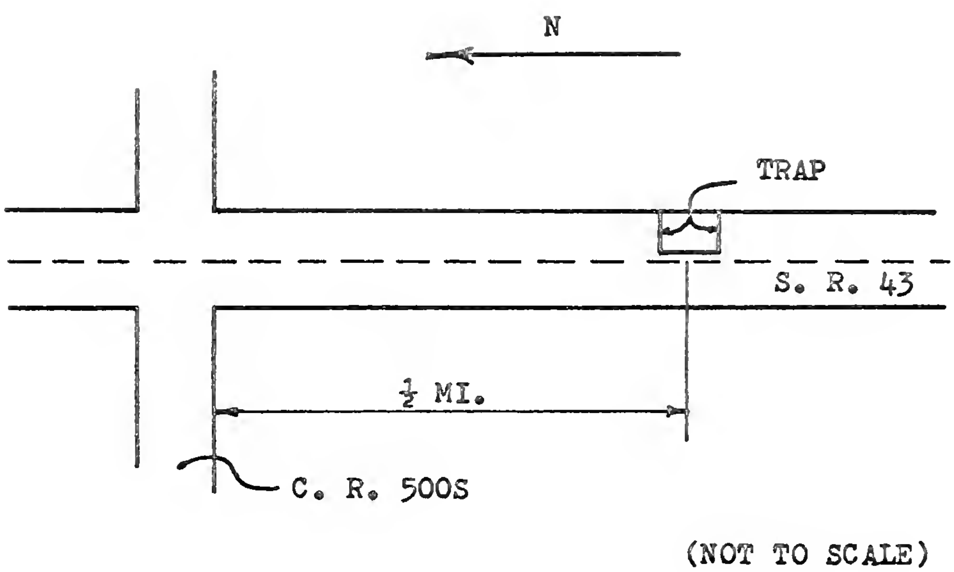


FIGURE 11, SITE NUMBER TWO

TABLE 12
SITE NUMBER TWO DATA

X_i (ft./sec.)	NO. OBS.
65	3
70	10
75	23
80	30
85	33
90	26
95	23
100	9
105	4

$\bar{X}_i$ = 84.91 ft./sec.

S = 9.065 ft./sec.
C.S. = .064

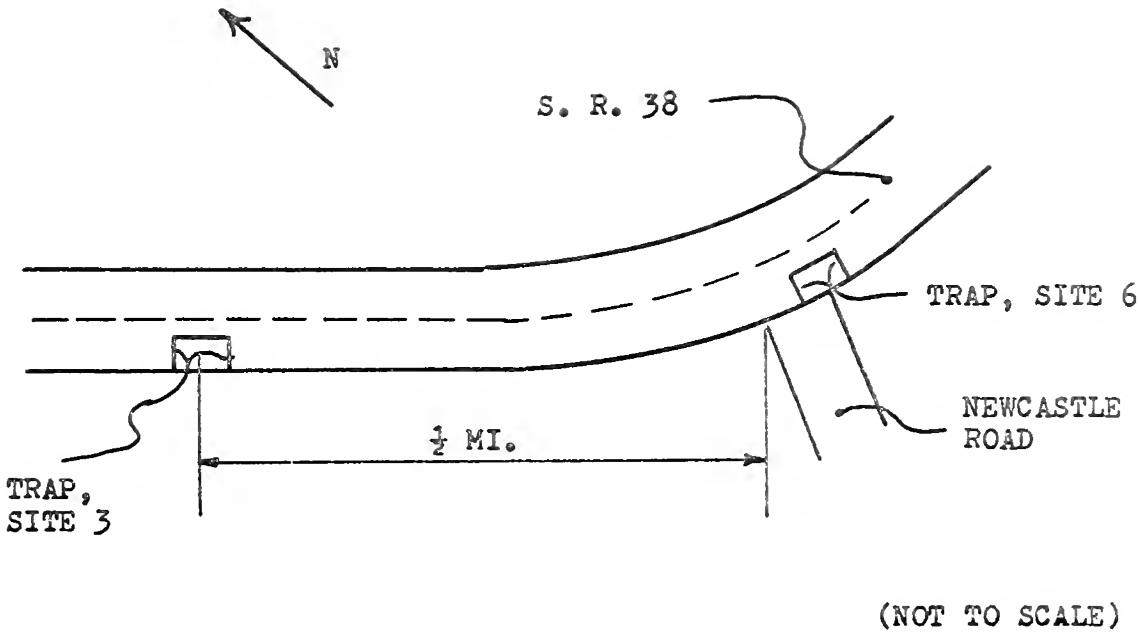


FIGURE 12, SITE NUMBER THREE

TABLE 13
SITE NUMBER THREE DATA

X_i (ft./sec.)	NO. OBS.
60	8
65	15
70	26
75	45
80	25
85	22
90	6

$\bar{X}_i$ = 75.24 ft./sec.

S = 7.456 ft./sec.

C.S. = -.093

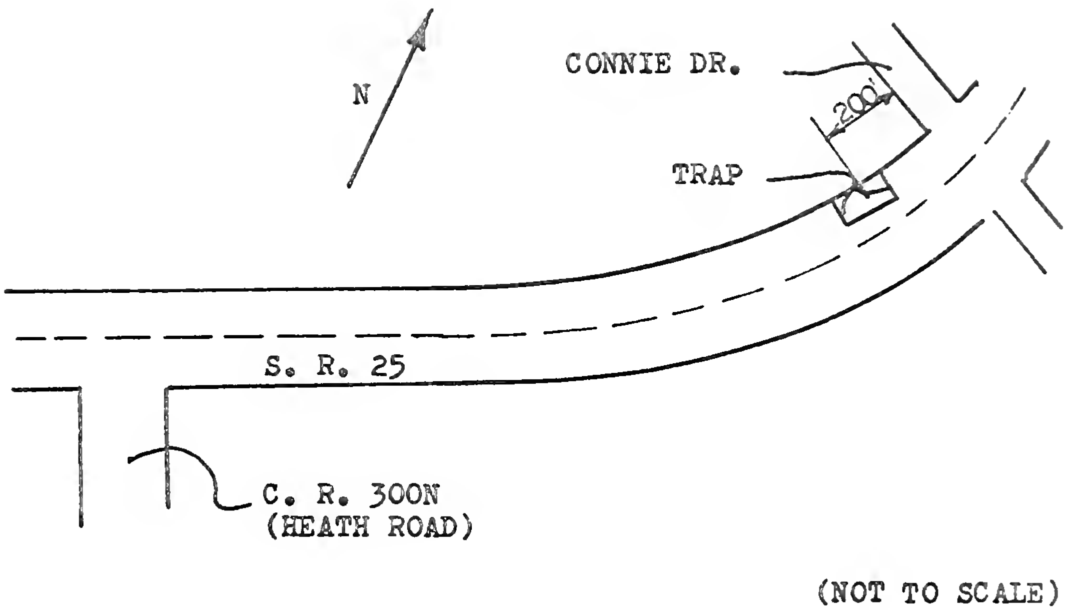


FIGURE 13, SITE NUMBER FOUR

TABLE 14
SITE NUMBER FOUR DATA

X_1 (ft./sec.)	NO. OBS.
55	8
60	17
65	26
70	27
75	15
80	9
85	4
90	0

$\bar{X}_1$ = 68.16 ft./sec.

S = 7.538 ft./sec.

C.S. = +.236

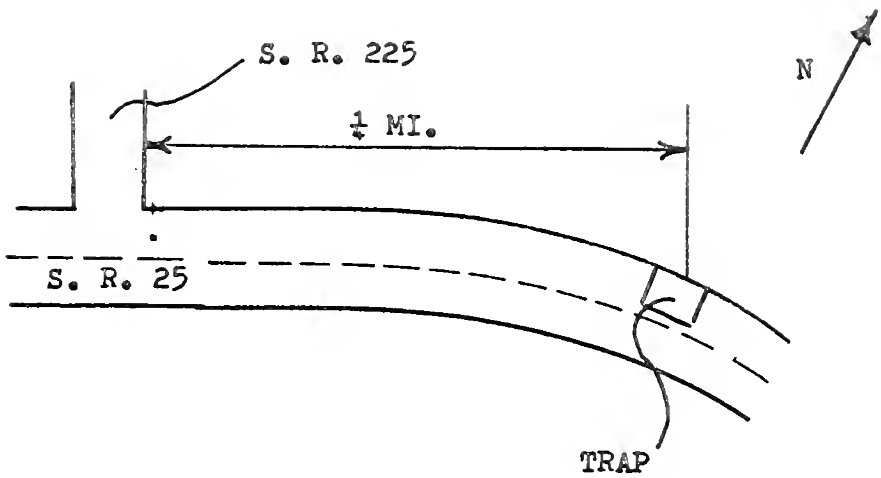


FIGURE 14, SITE NUMBER FIVE

TABLE 15
SITE NUMBER FIVE DATA

DAY DATA

X_1 (ft./sec.)	NO. OBS.
55	2
60	4
65	10
70	17
75	31
80	25
85	15
90	8
95	3

$\bar{X}_1$ = 76.48 ft./sec.
S = 8.376 ft./sec.
C.S. = -.123

NIGHT DATA

X_1 (ft./sec.)	NO. OBS.
50	3
55	5
60	9
65	16
70	33
75	30
80	18
85	9
90	2
95	1

$\bar{X}_1$ = 71.78 ft./sec.
S = 8.589 ft./sec.
C.S. = -.229

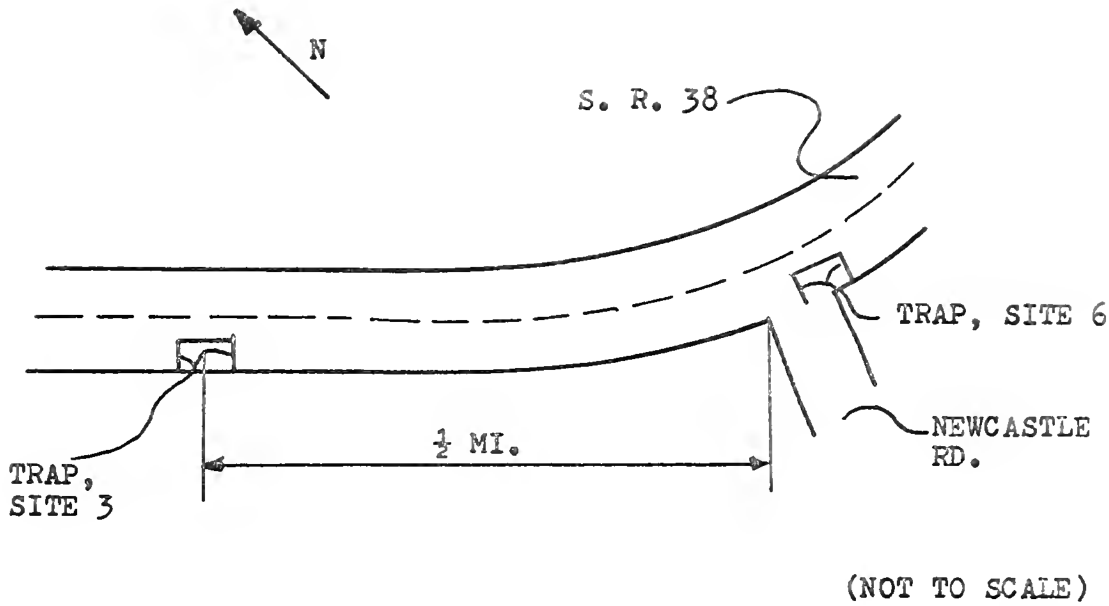


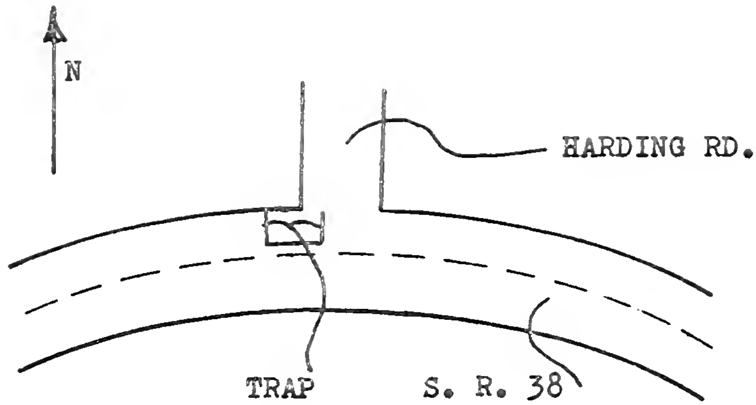
FIGURE 15, SITE NUMBER SIX

TABLE 16
SITE NUMBER SIX DATA

DAY DATA X_1 (ft./sec.)	NO. OBS.	NIGHT DATA X_1 (ft./sec.)	NO. OBS.
50	2	50	1
55	7	55	6
60	15	60	20
65	28	65	27
70	33	70	31
75	17	75	14
80	10	80	10
85	6	85	5
90	2	90	1

Day data:
$\bar{X}_1$ = 69.00 ft./sec.
S = 8.215 ft./sec.
C.S. = +.217

Night data:
$\bar{X}_1$ = 68.43 ft./sec.
S = 7.846 ft./sec.
C.S. = +.331



(NOT TO SCALE)

FIGURE 16, SITE NUMBER SEVEN

TABLE 17
SITE NUMBER SEVEN DATA

DAY DATA X_i (ft./sec.)	NO. OBS.	NIGHT DATA X_i (ft./sec.)	NO. OBS.
55	1	55	2
60	4	60	2
65	7	65	8
70	13	70	11
75	19	75	20
80	26	80	27
85	15	85	14
90	7	90	6
95	3	95	2
100	1	100	1

Day data:

$\bar{X}_i$ = 77.65 ft./sec.

S = 8.704 ft./sec.
C.S. = -.123

Night data:

$\bar{X}_i$ = 77.42 ft./sec.

S = 8.489 ft./sec.
C.S. = -.216

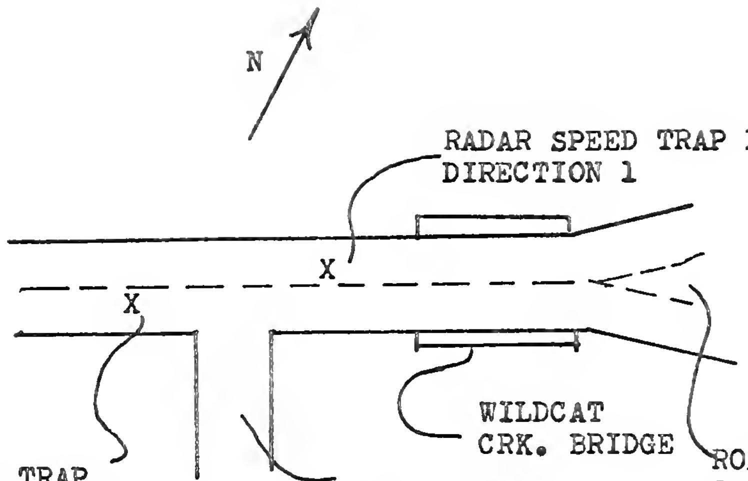
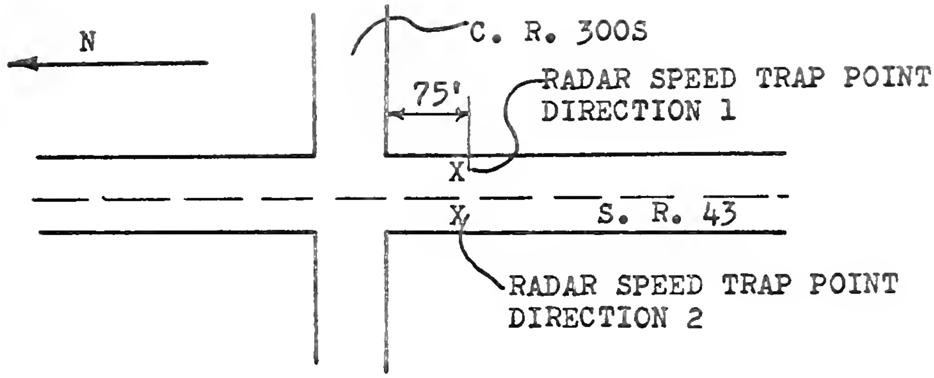


FIGURE 17, SITE NUMBER EIGHT

TABLE 18
SITE NUMBER EIGHT DATA

DIRECTION ONE DAY X (ft./sec.)	NO. OBS.	DIRECTION TWO DAY X (ft./sec.)	NO. OBS.	DIRECTION ONE NIGHT X (ft./sec.)	NO. OBS.
50	3	50	2	50	2
55	7	55	9	55	5
60	14	60	13	60	16
65	24	65	26	65	26
70	19	70	18	70	20
75	13	75	14	75	18
80	7	80	5	80	6
85	3	85	4	85	4
90	1	90	1	90	2
				95	1

Direction One Day	Direction Two Day	Direction One Night
$\bar{X}_1$ = 67.53 ft./sec.	$\bar{X}_1$ = 67.44 ft./sec.	$\bar{X}_1$ = 68.70 ft./sec.
S = 8.379 ft./sec.	S = 8.337 ft./sec.	S = 8.635 ft./sec.
C.S. = +.194	C.S. = +.293	C.S. = +.469



(NOT TO SCALE)

FIGURE 18, SITE NUMBER NINE

TABLE 19
SITE NUMBER NINE DATA

DIRECTION ONE DAY		DIRECTION TWO DAY		DIRECTION TWO NIGHT	
X (ft./sec.)	NO. OBS.	X (ft./sec.)	NO. OBS.	X (ft./sec.)	NO. OBS.
50	1	50	1	50	1
55	7	55	5	55	6
60	15	60	19	60	18
65	25	65	30	65	31
70	19	70	22	70	20
75	16	75	13	75	15
80	5	80	6	80	7
85	3	85	3	85	3
90	1				
$\overline{X}_1$ = 67.77 ft./sec.		$\overline{X}_1$ = 67.32 ft./sec.		$\overline{X}_1$ = 67.47 ft./sec.	
S = 7.857 ft./sec.		S = 7.189 ft./sec.		S = 7.369 ft./sec.	
C.S. = +.313		C.S. = +.345		C.S. = +.300	

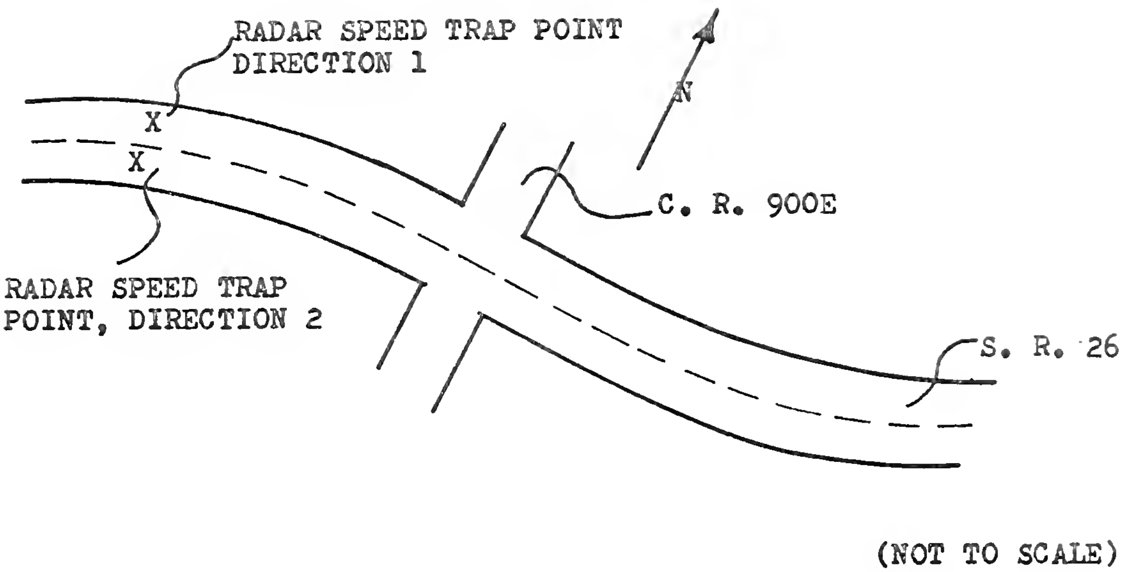


FIGURE 19, SITE NUMBER TEN

TABLE 20
SITE NUMBER TEN DATA

DIRECTION ONE
DAY DATA

X_i (ft./sec.)	NO. OBS.
50	1
55	5
60	14
65	24
70	21
75	17
80	7
85	1

$\bar{X}_i$ = 67.94 ft./sec.
S = 7.107 ft./sec.
C.S. = -.027

DIRECTION TWO
DAY DATA

X_i (ft./sec.)	NO. OBS.
50	2
55	7
60	22
65	27
70	24
75	18
80	7
85	1

$\bar{X}_i$ = 66.99 ft./sec.
S = 7.262 ft./sec.
C.S. = +.037

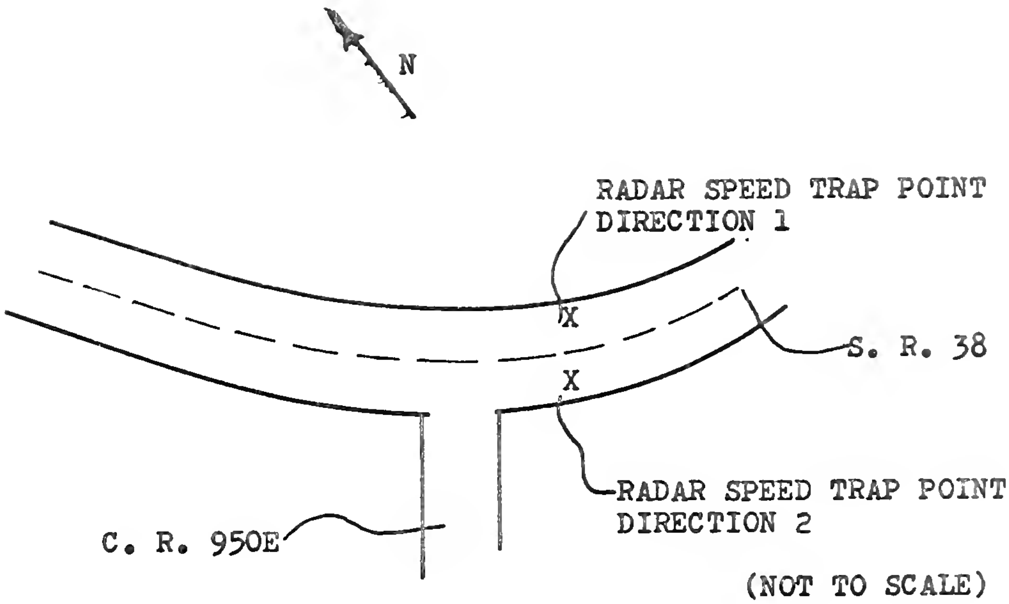


FIGURE 20, SITE NUMBER ELEVEN

TABLE 21
SITE NUMBER ELEVEN DATA

DIRECTION ONE
DAY DATA

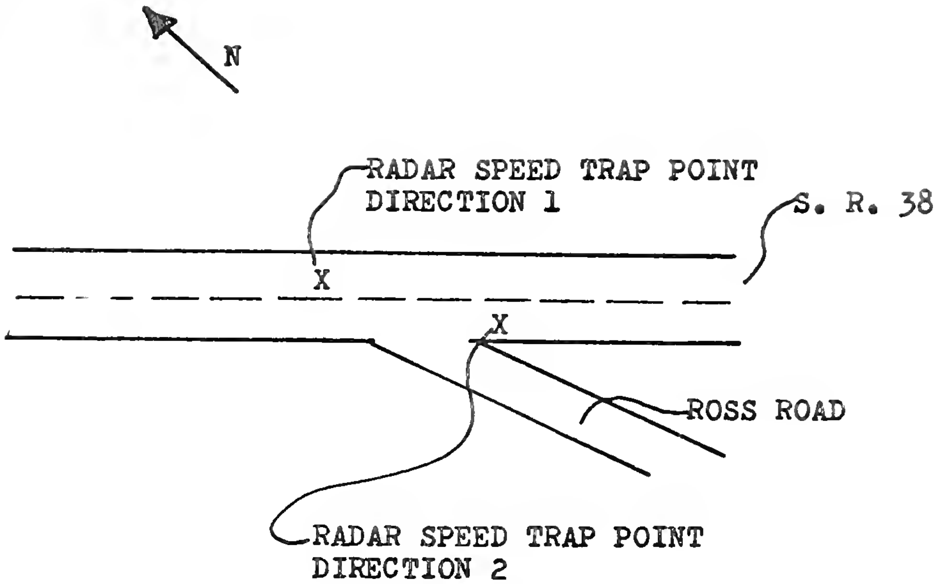
X_1 (ft./sec.)	NO. OBS.
50	3
55	6
60	21
65	25
70	23
75	19
80	7
85	2

$\overline{X}_1$ = 67.26 ft./sec.
S = 7.626 ft./sec.
C.S. = +.001

DIRECTION TWO
DAY DATA

X_1 (ft./sec.)	NO. OBS.
50	2
55	7
60	19
65	23
70	21
75	17
80	5
85	1

$\overline{X}_1$ = 66.84 ft./sec.
S = 7.332 ft./sec.
C.S. = -.003



(NOT TO SCALE)

FIGURE 21, SITE NUMBER TWELVE

TABLE 22
SITE NUMBER TWELVE DATA

DIRECTION ONE
DAY DATA

X_i (ft./sec.)	NO. OBS.
50	1
55	6
60	17
65	24
70	27
75	23
80	19
85	4
90	2

$\bar{X}_i$ = 70.04 ft./sec.
S = 8.211 ft./sec.
C.S. = +.031

DIRECTION TWO
DAY DATA

X_i (ft./sec.)	NO. OBS.
50	2
55	8
60	16
65	21
70	24
75	19
80	17
85	7
90	1

$\bar{X}_i$ = 69.70 ft./sec.
S = 8.005 ft./sec.
C.S. = -.043

COVER DESIGN BY ALDO GIORGINI